

INDIRECT PROGRAMMING OF DETECTOR  
FRAMING NODE

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH &  
DEVELOPMENT

The U.S. Government may have certain rights in this invention pursuant to the Portable Apollo X-Ray System for Military Applications Cooperative Agreement number DAMDD17-00-2-0009, awarded by the United States Army.

BACKGROUND OF THE INVENTION

5 The invention relates to a method, system, and apparatus for controlling, acquiring and processing digital radioscopic image data, and in particular to a method, system and apparatus for controlling and communicating acquired digital radioscopic x-ray image data to a computer running a non-real time operating system.

10 Medical imaging is a specialty that uses radiation, such as gamma rays, x-rays, high-frequency sound waves, magnetic fields, neutrons, or charged particles to produce images of internal body structures. In diagnostic radiology, radiation is used to detect and diagnose disease, while in interventional radiology, radiation is used to treat disease and bodily abnormalities.

15 Radiography is the technique of producing an image of any opaque specimen by the penetration of radiation, such as gamma rays, x-rays, neutrons, or charged particles. When a beam of radiation is transmitted through any heterogeneous object, the radiation is differentially absorbed depending upon varying object thickness, density, and chemical composition. The radiation emergent from the object forms a radiographic image, which may then be realized on an image detection medium, such as photographic film directly or by using a phosphor to first create a  
20 light image. Radiography is a non-destructive technique of testing a gross internal structure of an object, and is conventionally used in medical and industrial applications. Radiography is used to non-destructively detect medical conditions such

as tuberculosis and bone fractures, as well as manufacturing imperfections in materials such as cracks, voids, and porosities.

X-ray radiography finds particular usefulness in medical and industrial applications. X-rays are a form of electromagnetic radiation, and were accidentally discovered in 1895 by Wilhelm Conrad Roentgen. X-rays are alternately referred to as roentgen rays. In circa 1895, Roentgen found that x-rays propagate through an internal object such as a hand and expose photographic film, thereby revealing an internal structure. X-rays exhibit different properties than visible light rays, and were designated by Roentgen as "x-rays," with "x" referring to the unknown. For example, x-rays are not focused with a traditional optical light lens, but rather use sophisticated focusing techniques. Today, x-rays are categorized as electromagnetic radiation having a frequency range extending between  $2.4 \times 10^{16}$  Hz to  $5 \times 10^{19}$  Hz. Most x-rays have a wavelength smaller than an atom and therefore interact with matter in a granular fashion, that is, like bullets of photon energy. X-rays are absorbed by materials according to the exponential absorption law

$$I_x = I_0 e^{-\mu x} = I_0 e^{-(\mu/\rho)\rho x} \quad (1.0)$$

where  $I_0$  is the initial intensity of the x-ray beam;  $I_x$  is the intensity after passage through an object, the object having a thickness  $x$ , density  $\rho$ , linear absorption coefficient  $\mu$ , and mass absorption coefficient  $\mu/\rho$ .

X-rays are formed through celestial phenomenon, such as internal reactions of stars and quasars, and through electronic x-ray generation devices, such as x-ray tubes. X-ray tubes generally produce x-rays by accelerating a charged particle, such as an electron, through an electrostatic field and then suddenly stopping the x-ray through collision with a solid target. This collision ionizes the solid target by transporting closely held electrons to a higher energy state. As the electrons in the solid target return to their original energy state, x-rays are produced. X-rays are produced within x-ray tubes by accelerating electrons in a vacuum from a cathode

toward an anode, with or without particle beam shaping and accelerating through placement of electrodes.

The electronic detection of x-rays is generally referred to as electronic radiography or radioscopy. Prior to electronic detection, radiographic images were captured on photographic film or displayed on a fluorescent screen. Real time visual observation of x-rays on a fluorescent screen is referred to as fluoroscopy. However, as early as the 1930s photo-multiplier tubes (a form of vacuum tube) were developed to produce an electrical signal in response to received light. Photo-multiplier tubes generally respond well to optical range light rays and are therefore often optically coupled with a scintillating material to detect non-optical electro-magnetic radiation. The scintillating material converts non-optical radiation, such as gamma rays (emitted by radio-active isotopes used in nuclear medicine) and x-rays into optical radiation. Beginning circa 1980, photo-multiplier/scintillator detectors are generally being replaced by amorphous silicon based photo-cells.

Radioscopy includes one shot x-ray detection, also known as fluorography, and multiple shot x-ray detection, also known as fluoroscopy. Radio-mammography is a form of radioscopy in which the breast is vigorously compressed prior to exposure to maximize detail and minimize radiation exposure. Computed tomography ("CT"), also called computed axial tomography ("CAT"), is a form of radioscopy in which an x-ray tube is rotated around the body while emitting a narrow x-ray beam. The received x-ray beam information is then combined in a computer to produce a two or three dimensional anatomic medical image. Magnetic resonance imaging ("MRI") is a diagnostic procedure in which a high strength magnet aligns the spin of nuclei within cells of a body, such that each nuclei acts like a radio, both receiving and transmitting radio signals. External radio frequency signals are then applied to the body to disturb the spinning cellular nuclei. After the radio signal is stopped, the nuclei realign with the applied magnetic field while emitting faint radio signals. These faint radio signals correspond to different body tissues and are detected to produce an anatomical image.

Radioscopy and related medical diagnostic imaging technologies use precision control over penetrating radiation and well as precision timing for detection and processing of resultant image data. Medical diagnostic imaging generally acquires and controls a very large amount of image data, which in turn is communicated to computer processing equipment at a very high data rate. To provide control over the generation, detection, and processing of medical diagnostic imaging, computer workstations employ the use of a real time operating system ("RTOS") to control operation. A real time operating system, such as VXWORKS ® by Wind River Systems, Inc. of Alameda, CA, is an operating system that immediately responds to real time signaling events. On the other hand, non-real time operating systems, such as a WINDOWS ® platform or a UNIX ® platform, process operations in the form of tasks until the task is complete. Both WINDOWS ® and UNIX ® are non-real time, multi-task operating systems in which a processor or processors are continuously interrupted to respond to multiple task based system events. Due to the high speed of commercially available processors, multi-tasking operating systems may appear to control a number of simultaneous events. However, a multi-tasking operating system, by design, cannot respond in real time to the high through-put demands of real time processing equipment, such as used in medical diagnostic imaging.

#### BRIEF SUMMARY OF THE INVENTION

It is therefore desirable to provide an imaging system to control a radiation generation system and an image detection system in real time. The imaging system includes a host computer having a host memory and at least one host processor. The imaging system also includes a detector framing node, which is programmed to receive image data from a plurality of different flat panel detectors. The detector framing node communicates the image data to the at least one host processor over a communication bus independent of a host operating system.

It is further desirable to provide a detector framing node, including a computer communication interface to communicate image data with a host memory of a host computer over a computer communication bus. The host computer includes a

host processor running an operating system. The image data is communicated from the computer communication interface to the host memory independently from control of the host processor. The detector framing node also includes a control unit to receive a plurality of event instructions from the host computer through the computer communication interface. The event instructions selectively control a radiation generation system and an image detection system. The event instructions are executed in real time and at predetermined timing intervals.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an imaging system including a host computer, radiation generation system, and an image detection system;

FIG. 2 (PRIOR ART) is an elevated perspective view of a flat panel detector;

FIG. 3 (PRIOR ART) is an exploded sectional view of the flat panel detector of FIG. 2 taken along line III-III;

FIG. 4 (PRIOR ART) is an elevated prospective view of an x-ray detection panel removed from a protective metal casing;

FIG. 5 (PRIOR ART) is a schematic view of a photo cell array formed on an amorphous silicon panel;

FIG. 6 (PRIOR ART) is a block diagram of an electrical connection in an amorphous silicon single panel detector system;

FIG. 7 (PRIOR ART) is a block diagram of electrical connection in an amorphous silicon split panel detector system;

FIG. 8 (PRIOR ART) is a schematic diagram of a split panel, cardiac/surgical digital x-ray panel;

FIG. 9 (PRIOR ART) is a block diagram of column multi-chip modules and a reference and regulator board in a split panel detector system;

FIG. 10 (PRIOR ART) is a block diagram of a detector control board;

5 FIG. 11 (PRIOR ART) is a schematic diagram of a split panel radiography digital x-ray panel;

FIG. 12 (PRIOR ART) is a block diagram of electrical connection in an amorphous silicon single panel detector system;

FIG. 13 (PRIOR ART) is a schematic diagram of a single panel mammography digital x-ray panel;

10 FIG. 14 (PRIOR ART) is a block diagram of electrode connections in a split panel detector system having redundant row multi-chip modules;

FIG. 15 is a block diagram of control and data flow in an imaging system;

15 FIG. 16 is a block diagram of a software system for real time radiosopic imaging;

FIG. 17 is a block diagram of a hardware system for real time radiosopic imaging;

FIG. 18 is a block diagram of a detector framing node;

20 FIG. 19 is a table illustrating estimated processing capability for a 1024 x 1024 cardiac/surgical digital x-ray image;

FIG. 20 is a table illustrating available frame storage for 400 MByte of PC RAM memory;

FIG. 21 is a schematic illustration of a software tester interface executing a data acquisition and control software tester interface operation;

FIG. 22 is a block diagram of a hardware interface interacting with system components by way of a computer communication bus;

5                   FIG. 23 is a block diagram illustrating settings of a detector control board;

FIG. 24 is a schematic diagram of a field programmable gate array;

FIG. 25 is a block diagram of an event processor;

FIG. 26 is a block diagram of a data address processor;

10                  FIG. 27 is a block diagram of a detector framing node control unit in conjunction with a power on reset unit;

FIG. 28 is a schematic diagram of data being read out of a cardiac/surgical digital x-ray panel;

15                  FIG. 29 is a schematic diagram of data being read out of a radiography digital x-ray panel;

FIG. 30 is a schematic diagram of data being read out of a mammography digital x-ray panel;

FIG. 31 is a schematic diagram of cardiac/surgical digital image data being read into a plurality of static random access memories;

20                  FIG. 32 is a schematic diagram of radiography digital image data being read into a plurality of static random access memories;

FIG. 33 is a schematic diagram of mammography digital image data being read into a plurality of static random access memories;

FIG. 34 is a schematic diagram of memory allocation of a single cardiac/surgical digital x-ray image in a PC random access memory;

FIG. 35 is a schematic diagram of memory allocation of a single radiography digital x-ray image in a PC random access memory;

5           FIG. 36 is a schematic diagram of memory allocation of a single mammography digital x-ray image in a PC random access memory;

FIG. 37 is a schematic view of a PCI interface;

FIG. 38 is a block diagram of a image detection interface;

FIG. 39 is a block diagram of a fiber channel command data frame;

10           FIG. 40 is a block diagram of a fiber channel image detection data frame;

FIG. 41 is a block diagram of a fiber channel image done data frame;

FIG. 42 is a schematic view of a single channel of a real time bus interface;

15           FIG. 43 is a block diagram of a DFN clocking system;

FIG. 44 is a block diagram of a clock buffer;

FIG. 45 is a schematic diagram of a power on reset system;

FIG. 46 is a block diagram illustrating chip placement on a physical PCI card of a detector framing node;

20           FIG. 47 is a block diagram of a mapping of 16 MByte PCI address space;



FIG. 48 is a block diagram depicting top level states of a detector framing node and commands available for those states;

FIG. 49 is an event graph illustrating a typical sequence for image capture;

5           FIG. 50 is a table of a standard event set;

FIG. 51 is a block diagram of a Send event;

FIG. 52 is a table of reported Fiber Channel errors;

FIG. 53 is a block diagram of a Delay T event;

FIG. 54 is a block diagram of a Loop KN event;

10           FIG. 55 is a block diagram of a Loop KF event;

FIG. 56 is a block diagram of a Wait F event;

FIG. 57 is a block diagram of a Flag F event;

FIG. 58 is a block diagram of an End Q event;

FIG. 59 is an event graph for a mammography sequence;

15           FIG. 60 is a block diagram of an event queue;

FIG. 61 is an event graph of a Gated Cardiac Sequence;

FIG. 62 is a block diagram of an event queue;

FIG. 63 is an event graph of an autoscrub sequence;

FIG. 64 illustrates a top level Queue variable definition format;

20           FIG. 65 illustrates a frame level Queue variable definition format;

FIG. 66 is a format of a function call having defined ASCII names;

FIG. 67 is an example C++ user application explaining source code;

FIG. 68 is an example Perl script event sequence explaining source code;

5 FIG. 69 is a block diagram of a memory map architecture;

FIG. 70 is a schematic diagram of a constant memory format organizing constant data;

FIG. 71 is a block diagram of an operating system kernel and DFN driver interface;

10 FIG. 72 is a block diagram showing a memory configuration of PC RAM;

FIG. 73 is a block diagram showing how PC RAM looks for two allocated sequences.

#### DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1, a method, system, and apparatus are illustrated for  
15 controlling, acquiring and processing digital radiosopic image data. Imaging system 100 comprises radiation generation system 109, image detection system 112, host computer 114, and detector framing node 304. Host computer 114 includes monitor 119, host processor 115 and host memory 117. According to an embodiment of the present invention, imaging system 100 is an image detector monitoring system.  
20 According to another embodiment of the invention, the components of imaging system 100 function together as a single apparatus.

Radiation generation system 109 generates radiation to pass through object 106 and to be detected by image detection system 112. According to an embodiment of the present invention, radiation generation system 109 includes x-ray

generation unit 102 to generate and focus radiation 104 toward object 106. According to an embodiment of the present invention, radiation 104 takes the form of x-rays. According to another embodiment of the present invention, radiation 104 takes the form of a plurality of sequentially generated radiation bursts. According to an embodiment of the present invention, object 106 is in the form of the human body. Upon passage through object 106, x-rays 104 form radiographic image 108 for later detection. In general, x-rays are generated by x-ray generation unit 102 in response to control signals output from x-ray control system 110. Radiographic image 108 is received by image detection system 112 and converted into a digital radiographic image. The digital radiographic image is then output from image detection system 112 and transmitted to host computer 114. Host computer 114 provides electronic control to radiation generation system 109 and to image detection system 112.

Image detection system 112 includes flat panel detector 116 for receiving radiographic image 108. Flat panel detector 116 becomes heated during operation, and is therefore connected to power supply/chiller 118 for supplying power and cooling thereto. A digital radiographic image is output from flat panel detector 116 to host computer 114.

FIG. 2 (PRIOR ART) is an elevated perspective view of flat panel detector 116. Flat panel detector 116 is a single detector technology that provides an image receptor in x-ray radiography. For example, flat panel detector 116 replaces existing x-ray imaging films, such as plain film and spot film, for radiographic applications. Moreover, due to thin packaging, flat panel detector 116 replaces imaging intensifiers, video cameras, cine cameras, and photo spot imaging, etc. for digital radiography; and also for digital fluorography and digital fluoroscopy. The area of a flat panel detector 116 is 26 cm x 26 cm for a cardiac/surgical digital x-ray panel; 45 cm x 56 cm for a radiography digital x-ray panel; and 29 cm x 34 cm for a mammography digital x-ray panel. Glass plate 126 and metal casing 128 surround and protect the physical x-ray receptors, electronic detection equipment and associated electronics.

FIG. 3 (PRIOR ART) is an exploded sectional view of flat panel detector 116 taken along line III-III of FIG. 2. As illustrated, radiographic image 108 passes through glass plate 126 and is absorbed by x-ray detection panel 134. According to an embodiment of the present invention, x-ray detection panel 134 is a single panel x-ray detection panel. X-ray detection panel 134 is an amorphous silicon x-ray detection panel. X-ray detection panel 134 includes scintillating layer 130, which converts x-ray radiographic image 108 into optical radiographic image 132. Scintillating layer 130 is applied through vapor deposition onto x-ray detection panel 134, and in particular to amorphous silicon panel 136. Scintillating layer 130 takes the form of Gadolinium Oxysulfide,  $Gd_2O_2S:Tb$ ; or Cesium Iodide,  $CsI(Tl)$ . To receive high energy x-rays, the Cesium Iodide scintillating layer is used.

Amorphous silicon panel 136 is a photo-diode/transistor array that receives and converts optical radiographic image 132 into a plurality of representative image data values 138. Image data values 138 are received in analog form by interconnect electronics 140, and output from panel 136 as analog image data. Scintillating layer 130, amorphous silicon panel 136, and interconnect electronics 140 are formed on silicon glass substrate 144 through semiconductor technology known in the art. Together, scintillating layer 130, amorphous silicon panel 136, interconnect electronics 140, and glass substrate 144 form x-ray detection panel 134.

FIG. 4 (PRIOR ART) is an elevated prospective view of x-ray detection panel 134 removed from metal casing 128. As illustrated in FIG. 4 (PRIOR ART), amorphous silicon panel 136 forms a plurality of photo cells 146. Electrical information output from each photo cell 146 is transmitted to contact leads 148 by way of a plurality of corresponding contact fingers 150. Contact fingers 150 provide connection between contact leads 148 and amorphous silicon panel 136. As illustrated, scintillating layer 130 is formed on top of amorphous silicon panel 136.

X-ray detection panel 134 provides an array of light sensors with a small spacing between elements, and a large number of elements to adequately receive and detect projected x-ray radiographic images. Amorphous silicon panel 136 is a thin

film technology formed on a relatively large glass substrate 144. Eleven layers of amorphous silicon, various metals, and insulators are deposited by plasma enhanced chemical vapor deposition ("PECVD"), sputtering and meniscus coating to form field effect transistors ("FETs"), diodes, interconnects, and contacts. X-ray detection panel 134 forms panels for industrial and medical applications, and in particular, a cardiac/surgical digital x-ray panel, 20 x 20 cm; a radiography digital x-ray panel, 41 x 41 cm; and a mammography digital x-ray panel, 19 x 23 cm. The cardiac/surgical digital x-ray panel has 1024 columns x 1024 rows at 200  $\mu\text{m}$  pitch; the radiography digital x-ray panel has 2048 columns x 2048 rows at 200  $\mu\text{m}$  pitch; and the mammography digital x-ray panel has 1920 columns x 2304 rows at 100  $\mu\text{m}$  pitch.

Amorphous silicon provides a number of advantages over single crystal silicon for the formation of flat panel detectors, and is particularly distinguishable from single-crystal silicon. Amorphous silicon is characterized by having no definite form, and having no real or apparent crystalline structure. On the other hand, single-crystal silicon is grown as a single crystal, sliced into wafers, then polished for further refinement into integrated circuits. Amorphous silicon allows the formation of much larger panels than single crystal silicon because the formation of a single crystal is not used. However, amorphous silicon finds a 100 to 1000 times increase in defects, and a significant reduction in switching speed, which effect signal lag and signal offset characteristics. Scintillating layer 130, CsI(Tl), converts x-rays into optical rays and is evaporated onto amorphous silicon panel 136 to provide intimate contact therewith. CsI(Tl) forms a needle-like structure, which acts like a plurality of light pipes to prevent lateral spread of the light. Moreover, CsI(Tl) provides a transmission spectrum which is well matched to the quantum efficiency of amorphous silicon layer 136.

FIG. 5 (PRIOR ART) is a schematic view of photo cell array 152 formed on amorphous silicon panel 136. As illustrated, a plurality of photo cells 154 are sequentially triggered in response to a scan from row lines (n), (n+1), (n+2), ..., etc. Accordingly, corresponding outputs are read out along column lines (m), (m+1), (m+2), ..., etc. Each photo cell 154 includes a photo diode 156 and a field effect

transistor 158. Photo diode 156 is biased by way of bias lines 160 and discharged at the appropriate time by way of field effect transistors 158. The field effect transistors 158 control electrical discharge from the appropriate corresponding column lines. During operation, field effect transistors 158 are turned on by pulsing the appropriate row line to a high voltage, which is pulsed on the order of +11 V. Field effect transistors 158 are turned off by pulling the appropriate row line low, which is on the order of -11 V.

X-ray exposure creates electron-hole pairs in photo diodes 156 of amorphous silicon, x-ray detection panel 134 causing partial discharge. When field effect transistors 158 are then turned on, photo diodes 156 are recharged, and the amount of charge needed to recharge photo diodes 156 is measured. During operation, all row lines are turned off, i.e. to -11 V, during x-ray exposure. The row lines are then sequentially turned on, i.e. to +11 V. Analog to digital conversion of the signals on the appropriate column lines are pipe lined such that the outputs from row "n" are converted from analog information to digital information while row "n+1" is read out. The time period used for analog to digital conversion is on the order of the time used to read out each row line.

FIG. 6 (PRIOR ART) is a schematic diagram of electrical connections in flat panel detector 116 according to an embodiment of the present invention. Flat panel detector 116 includes a single amorphous silicon, x-ray detection panel 134, electrically coupled to a plurality of row multi-chip modules 164 and a plurality of column multi-chip modules 166. In response to sequential trigger signals from row multi-chip modules 164, all columns are simultaneously read out onto column multi-chip modules 166. Column multi-chip modules 166 convert analog readout signals from detection panel 134 into digital signals, which are in turn received by reference and regulator board 122.

Reference and regulator board 122 combines data output from column multi-chip modules 166 and outputs the same to detector control board 124. In summary, row multi-chip modules 164 turn field effect transistors 158 on and off

while column multi-chip modules 166 read out respective column signals. Reference and regulator board 122 supplies voltages to the row and column modules, while communicating control and data signals with respect to detector control board 124.

FIG. 7 (PRIOR ART) is a block diagram of electrical connection in flat panel detector 116 according to another embodiment of the present invention. Flat panel detector 116 schematically represents electrical connections, such as found in cardiac/surgical digital x-ray panels and radiography digital x-ray panels. As illustrated, flat panel detector 116 includes cardiac/surgical split panel x-ray detection panel 170 having a first panel portion 172 and a second panel portion 174. According to an embodiment of the present invention, split panel x-ray detection panel 170 is a cardiac/surgical split panel x-ray detection panel. First and second panel portions 172 and 174 are respectively triggered by row multi-chip modules 176. The output from first panel portion 172 is received by first column multi-chip modules 178 while the output from second panel portion 174 is respectively received by second column multi-chip modules 180.

FIG. 8 (PRIOR ART) schematically represents an embodiment of a split panel, such as split panel 170, as a cardiac/surgical digital x-ray panel 182. Cardiac/surgical digital x-ray panel 182 is formed from a first panel portion 184 and a second panel portion 186. Scan lines 0 to 511 appear in first panel portion 184 and also in second panel portion 186. Accordingly, as row scan line 0 is triggered, two row display lines, namely 0 and 1023, are simultaneously activated, and corresponding column output lines are output from first panel portion 184 and second panel portion 186. Likewise, as row scan line 1 is simultaneously activated in first panel portion 184 and second panel portion 186, corresponding column output lines are output from first panel portion 184 and second panel portion 186. As each scan line from each corresponding panel portion is activated, all column output lines from each panel portion output their respective values. Accordingly, as row scan line 0 is activated, column output lines 0 through 1023 are simultaneously output from first panel portion

184 while column output lines 1024 through 2047 are simultaneously output from second panel portion 186.

FIG. 9 (PRIOR ART) is a block diagram of column multi-chip modules 178 and 180 in conjunction with reference and regulator board 122. Column multi-chip modules 178 receive column signals output from first panel portion 172 while second column multi-chip modules 180 receive the column output signals from second panel portion 174. Accordingly, output from first column multi-chip modules 178 are combined by way of reference and regulator board 122 into combined signal output 188 to be received by detector control board 124. Likewise, column multi-chip modules receive column signals output from columns 1024 through 2047, which are then combined, and transferred to reference and regulator board 122. Reference and regulator board 122 combines the received signals then outputs the combined signal output 189. Collectively, the combined output signals from reference and regulator board, including output 188 and output 189, is output 195.

Reference and regulator board 122 includes first combination unit 192 for combining the outputs from multi-chip modules 178, and also second combination unit 194 for combining the outputs from multi-chip modules 180 corresponding to columns 1024 - 2047. Each multi-chip module 178 includes eight analog read out chips ("ARCs") 196, which provide a corresponding output to digital read out chips ("DRCs") 198. Thus, the output from the DRCs 198 are received by reference and regulator board 122.

Each ARC chip 196 utilizes a non-linear ramp-compare type analog digital converter. Each ARC chip 196 also receives 32 analog inputs and converts the data into eight channels of multiplexed twelve bit serial, grey scale encoded, data. Each DRC chip 198 then receives the multiplexed twelve bit serial grey encoded data from four ARC chips 196, performs serial to parallel conversion, and converts the grey code into twelve bit binary code. Each ARC chip 196 performs analog to digital conversion on the received data by comparing the signal from each data line in a comparator with a square root encoded ramp generated by a digital to analog converter



in common to all channels of all ARCs 196. The ramp voltage is increased in steps at a regular clock rate. When a ramp voltage matches a held voltage, a comparator trips, and a ramp counter value is latched. A time to convert each line of data is at least as great as the clock period times the minimum number of clocks used to convert all received column data lines. A voltage step of the ramp is increased as the signal increases. Quantum noise increases as the square root of each signal, and accordingly the step is increased quadratically so that the step size is a fixed proportion of the noise. By way of the foregoing, interface conditioning of control signals bound for row and column modules use a clock signal on the order of 32.5 MHz, for buffering data output between column modules 178 and 180 and detector control board 124.

FIG. 10 (PRIOR ART) is a block diagram of detector control board 124. In general, detector control board 124 receives twelve bit binary encoded data "A," corresponding to the output 188 from first column multi-chip modules 178. Detector control board 124 also receives twelve bit binary encoded data "B," corresponding to the output from second column multi-chip modules 180. Each of binary encoded inputs A and B are respectively received by registers 200 and 202. The outputs from registers 200 and 202 are then respectively transferred to decode look up tables ("LUTs") 204 and 206. Decode LUTs 204 and 206 are random access memories that perform a conversion from twelve bit binary quadratically encoded data into 16 bit binary linearly encoded data.

Operation of detector control board 124 is controlled by control unit 208. Control unit 208 is formed as a field programmable gate array ("FPGA"). Control unit 208 receives 16 bit pixel data from decode LUT 204 and 16 bit pixel data from decode LUT 206, then combines the pixel data into a 32 bit word. The 32 bit word is then output to image communication interface 210. According to an embodiment of the invention, image communication interface 210 is a fiber optic interface. Each 32 bit word is a combination of two 16 bit pixels, which were output separately from detector control board 124. The two pixels included in each 32 bit word may be side by side, as in a mammography single digital x-ray panel 224 (set forth in detail below and in reference to FIG. 13 (PRIOR ART)) or may be received from two separate

panels, such as output from first panel portion 184 and second panel portion 186 of cardiac/surgical digital x-ray panel 182. Radiography digital x-ray panel 228, set forth below and in reference to FIG. 11 (PRIOR ART), also includes two panel portions 230 and 232, and therefore follows the pixel format of cardiac/surgical digital x-ray panel 182. Split panel detector systems, corresponding to cardiac/surgical digital x-ray panel 182 and radiography digital x-ray panel 228, utilize data "reordering" before display on a conventional computer monitor. Data reordering is set forth in more detail below with regard to detector framing node 304.

Image communication interface 210 clocks 32 bit words received from control unit 208 into encoder/decoder unit 212. Encoder/decoder unit 212 converts each received 32 bit word into four ten bit words, each having error correction. The ten bit words are in turn received by transmitter 214. Transmitter 214 converts the received ten bit words into serial data having two bits, namely a clock bit and a signal bit. Transmitter 214 outputs the two bit data to fiber optic transceiver 216 for conversion into a fiber optic signal. The fiber optic signal is then transmitted on image detection bus 377 to a detector framing node, set forth in detail below. According to an embodiment of the present invention, image detection bus 377 is an optical fiber data link. Likewise, fiber optic transceiver 216 receives fiber optic signals from the image detection bus 377 and converts the received optical signals into a two bit data signal for reception by receiver 218. Receiver 218, in turn, converts the received two bit data, including a clock and a data signal, into ten bit words having error correction. The ten bit words are then received by encoder/decoder unit 212 for conversion into 32 bit words, which are stored in register 220 before transmission to control unit 208. An output from fiber optic transceiver 216 is also received by fiber optic signal detection unit 222 to maintain timing and protocol in cooperation with control unit 208. Control unit 208 is clocked by oscillator 224. Control unit 224 provides a control signal to reference and regulator board 122 by way of control line 226. Control unit 208 is a FPGA, Flex 10k50 manufactured by Altec, Inc. of San Jose, California.

FIG. 11 (PRIOR ART) schematically represents a split panel detector, such as split panel 170, as radiography digital x-ray panel 228. Radiography digital x-

ray panel 228 is formed from first panel portion 230 and second panel portion 232. Radiography digital x-ray panel 228 is 41 x 41 cm and has a total of 2048 columns x 2048 rows at 200 $\mu$ m pitch. The illustrated embodiment of flat panel detector 116 has twice as many row multi-chip modules 176 and twice as many column multi-chip modules 180 as the embodiment of FIG. 7. As each scan line is sequentially triggered, all column output lines 0 through 2047 simultaneously release pixel information from first panel portion 230, while column output lines 2048 through 4095 simultaneously release pixel information from second panel portion 232. Radiography digital x-ray panel 228 occupies approximately four times the surface area of cardiac/surgical digital x-ray panel 182. Radiography digital x-ray panel 228 is used for applications requiring a large surface area, such as a chest x-ray, while cardiac/surgical digital x-ray panel 182 finds application in procedures requiring a smaller surface area, such as cardiac fluoroscopy during surgical procedures.

FIG. 12 (PRIOR ART) is a block diagram of electrical connections in flat panel detector 116 according to another embodiment of the present invention. Flat panel detector 116 includes single panel 236, which is triggered by row multi-chip modules 238. Single panel 236 is read out by way of column multi-chip modules 240 and 242. Column multi-chip modules 240 and 242 are placed at opposite ends of single panel 236 such that even numbered columns are read out by column multi-chip modules 240 and odd numbered columns are read out by column multi-chip modules 242. Alternate read out of columns from opposite sides of single panel 236 enhances column density by allowing extra physical space for connection of single panel 236 to connecting hardware.

FIG. 13 (PRIOR ART) schematically represents an embodiment of a single panel detector, such as single panel 236, as a mammography digital x-ray panel 244. Mammography digital x-ray panel 244 is 19 x 23, cm having 1920 columns x 2304 rows at 100  $\mu$ m pitch. Mammography digital x-ray panel 244 has a total of 2048 columns. However, 1920 of the available 2048 columns are actual used. The remaining 128 columns are spaced throughout the columns in digital x-ray panel 244 to facilitate repair. Column output lines are alternately output from alternate sides of

mammography digital x-ray panel 244. This configuration allows ease in manufacture and simplifies assembly of connecting hardware to the mammography digital x-ray panel 244.

The 128 repair lines included in mammography digital x-ray panel 244 are used to repair open column address lines caused by manufacturing defects. The repair lines cross over both ends of the address lines and are separated by an insulating layer. A repair connection is facilitated by using a laser to weld an address line to a repair line through the insulating layer. In the case of row address lines, the row address lines are fully repaired using spare lines on flat panel detector 116, and therefore the readout system does not account for the repair. In the case of column repairs, data from repair lines is output in a different sequence from flat panel detector 116 such that the data is sorted by way of post processing.

FIG. 14 (PRIOR ART) is a block view of electrode connections in flat panel detector 116 according to another embodiment of the present invention. Flat panel detector 116 includes two sets of row multi-chip modules, namely first row multi-chip modules 248 and second row multi-chip modules 250. Unlike first and second column multi-chip modules 178 and 180, first and second row multi-chip modules 248 and 250 provide redundant connections across panel rows. Accordingly, if first or second panel portions 172 or 174 develop a defect, each row is optionally triggered from alternate sides thereof, such that data integrity of the row is preserved.

Each embodiment of flat panel detector 116 set forth above may be formed with redundant row multi-chip modules 250 to preserve data integrity in case of defects in panel formation.

FIG. 15 is a block diagram of real time radiosopic imaging system 300. System 300 is used in a variety of different medical applications and is also used in engineering, manufacturing, device test and repair. System 300 supports a plurality of different detector panels and particularly supports three different families of detector panel designs, namely for cardiac/surgical, radiography, and mammography applications. System 300 includes host computer 114 running user application 301

from script 309. The user application 301 communication with detector framing node 304 by way of acquisition DLL 313 and DFN device driver 314.

System 300 replaces a prior Image Detection Controller subsystem ("IDC"), which was based upon a TMS320-C80 processor and PC using real time operating system, VXWORKS ®. System 300 achieves 30 frames/sec acquisition and processing of 1024 x 1024 pixel images for fluoroscopy. Image detection bus 377 provides a 1.25 Gbit/sec fiber optic communication link between host computer 114 and detector control board 124. Image detection bus 377 particularly communicates between detector control board 124 of image detection system 112 and detector framing node ("DFN") 304, which is embodied as a peripheral component interconnect ("PCI") card suitable for connection to computer communication bus 302. According to an embodiment of the present invention, computer communication bus 302 is a PCI bus, and more particularly, a PCI bus operating at 33 MHz. According to another embodiment of the present invention, computer communication bus 302 is a PCI bus operating at 66 MHz. Detector control board 124 itself is embodied in a prior Apollo Common Detector Control Printed Wiring Assembly ("PWA"), manufactured by General Electric Medical Systems of Milwaukee, Wisconsin. The Apollo Common Detector Control PWA is used in a variety of applications including full field digital mammography ("FFDM"). Use of detector framing node 304 facilitates use of non-real time host computer 114 for image processing after image acquisition.

System 300 provides acquisition and control based on a commercial single or multiple processor PC hardware, such as the PENTIUM ® class processors manufactured by Intel, Inc., of Santa Clara, California. System 300 is a single data acquisition and control system for present and anticipated x-ray modalities, and supports application of the system to both engineering and manufacturing. A flexible architecture is provided to address needs of improved or future technology.

System 300 supports single and multiple frame acquisition of images with frame to frame control of supported detector parameters. A number of rows and a

number of columns in an acquired image are supported as input parameters, while providing control of data acquisition timing from an external frame trigger. System 300 acquires and views gain and offset corrected images at 30 frames/sec for a 1024 x 1024 array or 7.5 frames/sec for a 2048 x 2048 image. System 300 supports a non-real time operating system to test system functionality. According to an operative embodiment, the non-real time operating system is WINDOWS NT 4.0 ® supporting C++ language based applications. Modular software is structured to support a combination of applications and more direct hardware access for advanced users and programmers. User-coded test applications and generalized data acquisition routines are provided in separate modules.

System 300 provides archive capability for both raw, and gain and offset corrected data for single and multiple frames, including regions of single and multiple frames. A high resolution display of single and multiple frames and for regions of single and multiple frames is supported for both freshly acquired and archived data. Control of radiation generation system 109 or a grid controlled x-ray tube is supported through a real time bus interface. Real time triggering of the x-ray generator with 2 µsec timing resolution is supported along with programmable time delays of up to 16 seconds.

System 300 is a real time image data acquisition system in which the image data is acquired at a predetermined frame rate and the number of image frames to be acquired is determined at the time of acquisition. Before acquisition, the event compiler 408 sets up the frame rate by setting a time for executing a repetitive trigger over the real time bus 379. Likewise, the event compiler 408 sets up image acquisition by delaying the image request command to the image detection system 112 from the repetitive trigger. There is an integration period before scanning of the flat panel detector 116 is allowed to account for delays in the phosphor and collection of electron-hole pairs in the photodiode array. For real time data acquisition, there is minimal buffering during transfer of the image data from the image detection system

112 to the detector framing node 304, such that the image detection system 112 and the detector framing node 304 operate in synchronism.

According to an embodiment of the present invention, system 300 is configured as follows:

5	Computer:	Single/multiple PENTIUM ® class with PCI back-plane
	Operating System:	WINDOWS NT 4.0 ®
	Panel Designs: Apollo20:	1024 x 1024 - Data Reordered
		Apollo40: 2048 x 2048 - Data Reordered
		Mammo3: 2304 x 2048 - Bad column corrected
10		Smaller regions of interest
	Acquisition Modes:	Radiographic (isolated frames)
		Real Time (30 frames/sec for 1024 x 1024 image)
		Cine Loop (30 frames/sec for 1024 x 1024 image)
		Hardware debug
15	Image processing:	Offset, Gain, Bad pixel, Mammography bad column
	Display Req.:	8 bit gray scale including gamma correction
		Real time window and level
		Xia type display applications including zoom and pan
	X-ray support:	Simple 8 bit parallel real time bus
20	Archive support:	Hard drive and writable CD ROM drive

System 300 provides an improvement over the above prior IDC test system. Real time parameters, which were previously addressed in prior art VXWORKS ® operating system ("OS"), are now captured in detector framing node 304 operatively embodied as a single PCI card. Detector framing node ("DFN") 304 contains fiber channel communication circuitry, a buffer memory, a PCI communications controller, a real time bus to control the x-ray generator and a set of firmware programmable FPGAs for control of all circuits on DFN 304. An external PCI memory card is used in conjunction with DFN 304 to expand computer memory and provide storage for raw pixel x-ray image data. Operation of data acquisition and

subsequent data processing is through user written applications. A library of functions access hardware functionality and facilitate disparate needs of users in engineering, device repair and manufacturing areas.

FIG. 15 particularly illustrates operation of system 300 according to an embodiment of the present invention. An exact sequence of image frames and associated acquisition parameters is needed in advance for a particular image acquisition. Accordingly, one can specify, for each frame, the readout delay relative to x-ray pulse, the detector parameters, etc. A description of such attributes is captured in a frame sequence 310 of script 309. Program applications configure the data acquisition system through the frame sequence structure and then trigger the system to initiate acquisition of the frames. The frame sequence 310 will vary depending on the type of experiment being performed for each test. At a hardware level, the acquisition itself responds to a sequence of instructions from host computer 114. According to an embodiment of the present invention, the instructions are event instructions, known collectively as an event sequence 312. Each event instruction is executed at well-timed intervals. Event instructions trigger events that control external devices, such as through commands communicated over bus interfaces. For example, event instructions include 32 bit control words that are sent over image detection bus 377 to image detection system 112, and x-ray pulse trigger commands sent over real-time bus 379 to radiation generation system 109. Based on frame sequence 310, a complete list of such event instructions to be performed is constructed. The event sequence 312 need not be constructed in real-time and is therefore easily executed on host computer 114 running a non-real time operating system to support an event compiler. Once the event sequence 312 is known, the details are transmitted to DFN 304 for execution in real-time.

FIG. 15 is a block diagram showing the flow of control information and data through system 300 during image acquisition. As illustrated, frame sequence 310 is created by way of script 309. Frame sequence 310 is then translated into event sequence 312 using a compiler, which knows the details of the target control hardware. Event sequence 312 is received by test control unit 311, then sent to DFN



device driver 314, over computer communication bus 302, and finally to detector framing node 304. The event sequence 312 is then stored in preparation for execution. Event sequence 312 is initiated by sending a Begin Sequence command over computer communication bus 302. The extent of real-time control allotted to host computer 114 is confined to a determination of when event sequence 312 will begin. Subsequently, host computer 114 is completely removed from image acquisition.

Once event sequence 312 is complete, host computer 114 retrieves the acquired data in addition to various diagnostics and responses, which were recorded during execution of the event sequence. Therefore, host computer 114 is involved in pre- and post processing roles, and is therefore entirely removed from real-time operation.

As illustrated, detector framing node 304 communicates commands and responses with computer communication bus 302 by way of acquisition control unit 324. Event sequence 312 is communicated to event queue 322 by way of acquisition control unit 324. Event instructions are then transmitted to radiation generation system 109 from event queue 322. During application of the radiation, event instructions are transmitted to event queue 322 from image detection system 112. Radioscopic image data is also received by frame store 325 from image detection system 112, then transmitted to acquisition control unit 324 for transmission to host computer 114. In host computer 114, image data 316 is transferred through DFN device driver 314 and acquisition dynamic link library ("acquisition DLL") 313 before being subject to gain, offset, and bad pixel correction by gain, offset, and bad pixel correction unit 318. After completion of the correction, the image data is interfaced with test calculation unit 320 before being sent to disk archive 308.

FIG. 16 is a block diagram of a software system 328 for real time radioscopic imaging. User application interface ("API") 330 is software, which runs on host computer 114 and links acquisition hardware to user application 301. Acquisition DLL 313 is software communicating with elements within software system 328. Acquisition DLL 313 communicates bi-directionally with user API 330

and DFN device driver 314. As illustrated, DFN device driver 314 communicates bi-directionally with detector framing node 304, which in turn communicates with radiation generation system 109 and image detection system 112. User API 330 also communicates with display library 335, image process library 336 and archive library 337.

For communication with software system 328, instructions are prepared in excel user interface 339, and then translated by translator 331 before being received by Perl script unit 333. Event compiler 408 also outputs information to binary file unit 329. The output from binary file unit 329 is then loaded into EAB memory 474 on EP 374 under control of user API 330, Acquisition DLL 313, and DFN device driver 314. The binary file contains information to control event sequence 312. Event sequence 312 can be debugged on the high resolution display 338 by creating the timing information in the event simulator 407.

FIG. 17 is a block diagram of a hardware system 340 for real time radioscopic imaging. Hardware system 340 includes data acquisition and control hardware. Hardware system 340 is also a block diagram of tester hardware. Except for detector framing node 304, remaining hardware components are commercial off-the-shelf ("COTS"). Host computer 114 is controlled by host processor 115. According to another embodiment of the present invention, host processor 115 is formed as a pair of processors operating together. According to yet another embodiment of the present invention, host processor 115 is formed as a plurality of interconnected processors. Host memory 117 is formed by computer RAM 334 and PCI RAM card 336 set forth in greater detail below. Hardware system 340 receives data of 1024 x 1024 images (2 MByte) at 30 frames/sec, which corresponds to a data transfer rate of 60 MBytes/sec. Computer communication bus 302 has a transfer rate of 132 MByte/sec. Because of arbitration of first PCI sub bus 342, the transfer rate across computer communication bus 302 is less than 132 MByte/sec.

Hardware system 340 includes DFN 304, which is connected to computer communication bus 302. Computer communication bus 302 is comprised of

first PCI sub bus 342 and second PCI sub bus 346, connected by bridge 344. Second PCI sub bus 346 interconnects with disk archive 308 by way of small computer systems interface ("SCSI") 348. Second PCI sub bus 346 also connects to high resolution display 338 by way of PCI graphics card 350. Second PCI sub bus 346 connects to host processor 115, accelerated graphics port ("AGP") 356 and computer RAM 334 by way of bridge 352. AGP 356 is a high speed graphics port for connection of monitor 119 by way of video card 358.

In a real time mode, PCI 302 bus arbitration will slow the data transfer rates on first PCI sub bus 342 and second PCI sub bus 346 such that the continuous display rate of 30 frames/sec will likely be determined by arbitration conflicts. In hardware debug mode, a test of DFN hardware is started from host processor 115 by sending a Command to DFN 304. The results of this test (i.e. bad, good) are returned to host computer 114. This hardware debug mode is used to run the Built-in-self test ("BIST") described later in the specification. In real time mode, data is sent directly from a buffer memory on the DFN 304 to computer RAM 334 and displayed almost simultaneously.

FIG. 18 is a block diagram of detector framing node 304. Image detection interface 376 communicates with detector control board 124 (described above with reference to FIG. 10 (PRIOR ART)) to receive image data therefrom. According to an embodiment of the present invention, image detection interface 376 is a fiber optic interface. DFN memory unit 380 includes a total of ten 8 Megabit SRAMs. DFN memory unit 380 includes five frame buffer memory units 381, with each frame buffer memory unit 381 comprising two 8 Megabit SRAMs. When one frame buffer memory unit 381 becomes full the data is read out of that unit to computer communication bus 302 and data is then written to another frame buffer memory unit 381. A large image, such as 2048 x 2048, is read directly into DFN memory unit 380 with data reordering occurring during a data write under control of data acquisition processor ("DAP") 372. DAP 372 and event processor ("EP") 374 are FPGAs, which are used to control real-time bus interface 378. Real time bus interface 378 is connected to real time bus 379. EP 374 also controls read and write of data with

respect to image detection bus 377 by way of image detection interface 376. Computer communication interface 382 is embodied as a PCI interface in the form of an application specific integrated circuit ("ASIC") to control bus communications between local bus 384 and computer communication bus 302. As illustrated, fiber optic test connector 390 interfaces with the bus connecting image detection interface 376 and DFN control unit 370.

Imaging system 100 provides support for several different users, including support for different x-ray image panel designs and applications. Accordingly, flexible testing is provided to support different image acquisition modes. The acquisition modes used by imaging system 100 are described in terms of the target applications and users. For example, support for, at least, four specific modes is presented: Hardware Debug, Panel Setup, Single Frame, and Real Time. However, modal capability of imaging system 100 is more generically specified in terms of data management and bandwidth considerations.

FIG. 19 is a table illustrating estimated processing capability for a 1024 x 1024 cardiac/surgical digital x-ray image. The various modes of operation are shown with a preliminary estimate of performance. Two cases of interest are distinguished. One is a real time case, where the bandwidth of the hardware acquires, corrects and displays a single pipe-lined sequence within an intended frame rate. In a second case, called Post Process, bandwidth of the hardware is insufficient given the complexity of the algorithm and/or the panel size. As a result, the data is acquired and stored in real time, processed during a delay period, and finally displayed at an intended frame rate.

As illustrated in FIG. 19, "gbr" refers to the three particularly supported correction algorithms, namely corresponding to cardiac/surgical digital x-ray, radiography digital x-ray, and mammography digital x-ray, other than offset correction. These are: gain correction (g), bad-pixel correction (b), and repair line correction (r).

FIG. 20 is a table illustrating available frame storage for 400 MByte of either PC RAM memory or memory on a separate PCI memory card. Test modes include a hardware test mode to access status and functional information of PCI hardware cards and external devices connected through DFN 304. This includes tests of the DFN 304 card itself, an external PCI memory card, image detection bus 377, detector control board 124, and real time bus 379 (for communications with radiation generation system 109).

Panel setup mode is used at the beginning of panel test, during panel alignment, where near real time visualization is valuable to ensure proper flex contacts to image detection system 112. Here, data acquisition occurs with reordering in DFN 304 as a single processing operation. There is direct transfer of the data to computer RAM 334, bypassing PCI RAM card 336. In other applications data is passed to PCI RAM card 336 or another commercially available image processing card rather than computer RAM 334. Once the data is in the PCI RAM card 336, the data is accessible by host processor 115 at a later time for processing. In the case of a commercially available image processing card, the data is further processed in that card before delivery to host processor 115 via computer communication bus 302. As a result, data is displayed at 30 frames/sec for a 1024 x 1024 image, or 7.5 frames/sec for a 2048 x 2048 image. There is a one or two frame delay between acquisition and display of the image. For those applications where the data is transferred directly to host computer 114, the available computer RAM 334 limits the number of frames stored.

A single frame mode provides a typical application including mammography digital x-ray and radiography digital x-ray testers where a relatively small number of frames are acquired. One or more frames are captured and reordered in DFN memory block 380 on the DFN 304, transferred to computer RAM 334, and processed in host processor 115 to correct gain, offset, bad columns, channels of ARCs 196 and bad pixels. Corrections to channels of ARCs 196 include gain and offset correction to correct ARC gain, which varies from channel to channel. After correction, the frames are displayed on high resolution display 338. The delay between

the completion of data acquisition and display is expected to be less than 0.25 sec for a single 2048 x 2048 image. After acquisition, the small number of frames would still be in computer RAM 334 and would be available to the application after display.

An embodiment of a real time mode is a cardiac/surgical digital x-ray tester or a radiography digital x-ray tester having a real time display, such that data is acquired, reordered, processed and displayed sequentially. The delay between data acquisition and display is on the order of 0.03-0.06 secs for a 1024 x 1024 image. A 1024 x 1024 image is supported at 30 frames/sec. In this mode every nth frame is stored and displayed, where  $n=1$  to 10, while having an ability to store the last 60 frames of 1024 x 1024 data under operator control.

FIG. 21 is a schematic illustration of software tester interface 400 executing a data acquisition and control software tester interface operation. Software tester interface 400 includes a tester application 402 to access acquisition hardware 418 through tester resources 404. Tester resources 404 include a batch process interface 406, a programming interface library 337 and a hardware drivers library 339. Batch process interface 406 includes configuration files 412, sequence files 414, and calibration files 416. The software tester interface 400 is a direct interface to the hardware drivers library 339 and programming interface library 337, which provides a convenient set of high level C-calls for sequence acquisition. The hardware driver library 339 is also a software library and contains an event compiler, which provides the translation of a user-defined frame sequence to detailed event instructions on detector framing node 304 to handle real time events.

Programming interface library 337 is a programming interface to assist the writing of a tester application with respect to image acquisition. The programming interface has a well defined subset of functionality whereas the hardware interface accesses the full functionality of the tester. The programming interface library 337 contains high level functions, which interface between the hardware drivers and the user application, i.e. tester application 402. This layer contains functions to poll the hardware devices and report back status information. This layer also enables the user

to configure the acquisition hardware in a particular acquisition mode and to initiate the acquisition sequence.

The details of the image acquisition are specified by a structure defining the frame sequence. This structure is passed by a user program to an acquisition subroutine provided in the programming interface. The returned object is a pointer to a data and header, which is then available to the user program. Alternatively, the data is directly archived to disk. Convenient interfaces to various possible corrections and options for display are available at this level. Header translation from device specific to descriptive values occur in this layer.

Examples of library functions available for a user programs include:

- 1-Get hardware status
- 2-Configure acquisition system
- 3-Acquire and display data sequence (raw)
- 4-Acquire and display data sequence (corrected)
- 5-Store data sequence to disk

Batch process interface 406 is a subset of a programming interface from programming interface library 337, which provides a text based mechanism for image acquisition. Configuration files 412 and sequence files 414 are text files, which define all information to carry out acquisition of a sequence of frames. The separation of this information into two files ensures that there is no misunderstanding on which frame-to-frame parameter variation will be supported. In the simplest mode of operation, the user is authorized to alter these files in a common text editor and then initiate the acquisition with a command. The returned header will reflect the acquisition parameters as defined in the configuration and sequence files.

Information which is constant across a sequence is contained in configuration files 412. Examples include firmware revision numbers, serial numbers, panel type and process stage, tester location. In addition, the information contained in the configuration files 412 includes reordering, correction, archive, and display options. Calibration files 416 contain all information to correct data for gain, offset,

bad pixel and channel gain of ARCs 196 on a pixel by pixel basis. In contrast, sequence files 414 contain the specific acquisition parameters of each frame in the sequence. These specific acquisition parameters include all the detector parameters and event timing.

5                   FIG. 22 is a block diagram of hardware drivers interface 410 interacting with system components by way of computer communication bus 302. Hardware drivers interface 410 includes commands as a main element in an event compiler 408, which translate a structure describing the frame sequence to a detailed set of event instructions, which are loaded into a queue on event processor 374 of  
10   detector framing node 304. Hardware drivers interface 410 includes event compiler 408, hardware debug toolkit 409, and a plurality of external device supports 411 for external devices. The external device supports support a plurality of external devices, such as detector framing node 304, high resolution display 338, etc. The hardware drivers interface 410 communicates with the external devices by way of bus interface  
15   Commands are available to send elemental messages to the external devices and pass back reply messages to the user application, e.g. detector messages and x-ray status messages. The development of the test system involves a set of software to debug and validate the individual pieces of hardware. This software is formalized and documented, and provided as part of the tester product as a tool kit to assist the  
20   support of the system by the user and maintenance personnel. Event compiler 408 is a software package that takes a frame sequence file and generates a set of control words to be loaded into DFN control unit 370 in DFN 304 to achieve the desired control functionality.

As illustrated in FIG. 17, hardware system 340 provides hardware and  
25   software with window level control for driving a commercial display driver card to view data acquisition results. The display displays both raw and processed archived images. The displayed data is 8 bits including gamma correction for display phosphor non-linearity. At a lowest magnification there is a one to one correlation between the display least significant bit ("LSB") and the least significant bit received from image  
30   detection system 112. A second monitor 368 is used to provide a user interface. Image



display supports Xia functionality, such as pan, zoom and pixel amplitude display. Row and column numbers of a selected pixel are optionally displayed along with calculation of statistics for a region of interest.

Disk archive 308 is used for short term storage and is embodied as either a removable disc drive or writable 650 MByte CD ROM. Capability for archiving both raw and processed images along with a header of descriptive information is supported.

Host computer 114 includes network support and is configured with an 10/100 Mbit/sec Ethernet card and software for data transfers via the Ethernet. Other devices are supported, such as LEDs used in panel test or collimators. Such support includes an additional PCI card and driver in the C program to collect or send data to the additional PCI card.

An 8 bit real time parallel I/O bus 379 is used to control or receive control from radiation generation system 109. Timing is provided by DFN control unit 370. Delays between the x-ray generation and data acquisition on Detector Control Board 124 are provided under software control. Synchronization of data acquisition with x-ray generation is therefore provided. X-ray generator voltage and current may be set under software control as well as operations to turn the x-ray generation unit 102 on and off via the tester hardware and software. Pulsed control of x-ray generation unit 102 with a control grid is provided. Control of current and voltage from pulse to pulse is provided with a 200 msec time resolution. Alternatively a separate interface to x-ray generator 102 is provided.

The 8 bit real time parallel I/O bus 379 is also used to control x-ray generator 102 of radiation generation system 109. Timing is provided by DFN control unit 370 on DFN 304. Delays between the x-ray generation and data acquisition on Detector Control Board 124 are provided under software control. The x-ray generator 102 is triggered as an on/off signal. Alternatively, generator voltage, current and

exposure time are set and measured. Likewise, the 8 bit real time parallel I/O bus 379 is used to control an x-ray generator for radiography digital x-ray.

FIG. 23 is a block diagram illustrating configuration settings of detector control board 124. Detector framing node 304 interfaces with detector control board 124 through fiber channel interface hardware and supports a communication rate of 1.25 GHz. The user is able to control data acquisition by controlling the configuration settings of FIG. 23.

Referring to FIG. 1 and FIG. 18, detector framing node 304 allows host computer 114 to interface to radiation generation system 109 and image detection system 112. Accordingly, detector framing node 304 supports a fiber channel interface for communication to detector control board 124, the RS-485 real time bus interface 378 for communication to radiation generation system 109, and the computer communication interface 382 for communication to host computer 114. A block diagram of DFN 304 architecture is shown in FIG. 18 and illustrates the interfaces just described. In addition to the hardware for interface communication, two FPGAs control the flow of data through the card. The EP 374 contains a sequencer, which orchestrates detector and x-ray event instructions in real time. EP 374 also contains a command interpreter which communicates with host computer 114. The DAP 372 controls the routing of image data during frame readout and acts as a bridge chip between image detection bus 377, and local bus 384 and DFN memory unit 380.

Detector Framing Node 304 supports an architecture based upon programmable logic, in the form of DFN control unit 370. The DFN control unit 370 is formed from a pair of FPGAs, which are preferable over embedded processors. First, firmware for the FPGAs is written in VHDL hardware description language, which remains largely platform independent, for integration into a single ASIC. Secondly, VHDL simulation of detector framing node 304 reduces hardware development time. Third, the use of programmable logic devices helps to simplify design of DFN 304 and allows for custom routing of signals between the various client buses on DFN 304, namely image detection bus 377, computer communication

bus 302 and real time bus 379. Use of configurable logic simplifies design, simulation, and programming.

Detector framing node 304 uses a 32 bit, 33 MHz computer communication interface 382 to support a transfer rate of 60 MBytes/sec. According to an alternate embodiment, computer communication interface 382 is a 64 bit PCI interface. DFN memory unit 380 includes five frame buffer memory units 381 embodied as 2 MByte frame buffers. Each frame buffer memory unit 381 facilitates sustained (transfer may occur in bursts) data transfer from image detection bus 377 to computer communication bus 302 without loss or data interruption. The use of five buffers provides a margin for capture of a single mammography digital x-ray image without loss or data interruption. Real time bus 379 is an 8 channel full duplex real-time bus interface (RS-485).

Detector framing node 304 controls radiation generation system 109 through serial connection. In other words, detector framing node 304 is in series with external control of the x-ray generation. Detector framing node 304 supports the following: image detection interface 376 operating at 1.25 GBaud rate; 32 bit, 33 MHz computer communication interface 382; 8 bit RS-485 real-time bus interface 378; real-time sequencing of detector and x-ray event instructions; built in self test ("BIST"); field reconfiguration; power-down capability; sustained data throughput of 60 MBytes/sec; software reset; and monitoring of key signals. BIST is provided on all five frame buffer memory units 381, i.e. 10 SRAMs; electrical loopback test on image detection bus 377; and electrical loopback test on real time bus 379.

Major components of detector framing node 304 are embodied according to Table 1 set forth below:

Table 1

Name	Part Number	Manufacturer
Computer 382	PCI 9054	PLX Tech.
EP 374	EPF10K200EFC600-1	Altera
DAP 372	EPF10K200EFC600-1	Altera

	EEPROM 530, 532	EPC-2	Altera
	10 SRAM chips	K7M803625M-QC90000	Samsung
	F.O. transceiver 560	MDX-19-4-1	Methode
	F.O. transmit unit 562	TQ9501	Tri-Quint
5	F.O. receive unit 564	TQ9502	Tri-Quint
	Encoder/decoder unit 566	TQ9303	Tri-Quint
	PCI eeprom 606	NM93CS66LEN	Fairchild
	Real time bus interface 378	SN75ALS171DW	Texas Instruments
	clock buffer 576	49CT3805PYI	IDT
10	power on reset unit 534, 536	MAX6306UK29D3-T	Maxim

For testing and monitoring, detector framing node 304 supports self temperature monitoring, unique board ID, layout revision number, JTAG port 542 for reconfiguration of DFN control unit 370, JTAG port 544 for reprogramming of FPGA eeproms, visual diagnostic indicators, connector for access to local bus, connector for access to image detection bus 377, and a connector for access to DAP/EP test bus 384.

EP 374 is an FPGA 200 K gate Altera Flex family, -1 speed grade, supporting a 32 bit local data bus with bus master capability. EP 374 also supports a 20 bit local address bus, a 32 bit test bus, a 32 bit direct link to DAP 372, a 32 bit fiber channel receive bus, a 32 bit fiber channel transmit bus, a twelve bit fiber channel control bus, a fiber channel reference clock input - 31.25 MHz, a local bus clock input - 36/33 MHz, a 2.5 V core for low power operation, and a 3.3 V TTL compatible interface. EP 374 drives eight visual diagnostic indicators, and also interfaces to on-board temperature sensors. Likewise, EP 374 reads an available 5 bit layout revision code and interfaces to a board ID chip.

DAP 372 is a 200 K gate Altera Flex family, -1 speed grade, supporting a 32 bit local bus, a 20 bit address bus with bus master capability, a 32 bit fiber channel receive bus, fiber channel reference clock input - 31.25 MHz, local bus clock input - 36/33 MHz, local bus arbitration logic, SRAM address bus, SRAM data

bus, SRAM control lines, SRAM clocks, JTAG bus controller, 32 bit test bus, 2.5 V core for low power, and 3.3 V I/O for TTL compatibility.

FIG. 18 is a block diagram of detector framing node 304. DFN 304 allows host computer 114 to interface to radiation generation system 109 and x-ray image detection system 112 in order to control x-ray digital image acquisition. DFN 304 includes image detection interface 376 and real time bus interface 378. DFN control unit 370 is comprised of two FPGAs to control the flow of data through DFN 304. EP 374 contains a sequencer to orchestrate detector and x-ray event instructions in real time. EP 374 also contains a command interpreter to communicate with host computer 114 over computer communication bus 302. DAP 372 controls routing of image data during frame readout and acts as a bridge chip between image detection bus 377, and local bus 384 and DFN memory unit 380.

FIG. 24 is a schematic diagram of a field programmable gate array ("FPGA") 440. The majority of functionality incorporated into DFN 304 is realized using two FPGAs 440 as DFN control unit 370. FPGAs 440 provide fast custom logic and a large number of user I/O, which are used for bus intensive applications. All logic on DFN 304 is described using the VHDL hardware description language, and is highly portable across different FPGA architectures. The specific FPGAs used for DFN 304 include a matrix of logic array blocks ("LABs") 442 with a large amount of configurable interconnect. As illustrated in FIG. 24, each LAB 442 is further divided into eight logic elements ("LE") 444 with associated local interconnect resources. Each LE 444 contains a four input SRAM based look up table for realizing combinatorial logic functions and is coupled to a single flip-flop. Signals are routed into and out of user I/O pad cells, which are themselves configurable to change parameters, such as output rise time and open-collector output. FPGAs 440 are selected for logic density and speed of operation.

FIG. 25 is a block diagram of EP 374. EP 374 is used as a control device on DFN 304. As illustrated in FIG. 25, EP 374 is comprised of a number of sub

units, which communicate with one another to control various aspects of DFN 304 functionality. Each of these sub units is discussed in turn.

EP control unit 450 is responsible for overseeing operation of EP 374 and in coordinating interactions between local bus 384, fiber channel interface 480 and event sequencer unit 470. EP control unit 450 maintains a plurality of control registers 454, which parameterize the various operations taking place in EP 374. EP control unit 450 also maintains a plurality of error registers 452, which are used to report any problems in execution to host computer 114. EP control unit 450 coordinates interaction between error registers 452 and control registers 454 by way of master control unit 456.

PCI/local bus interface unit 460 is responsible for hosting communication between EP 374 and local bus 384. Through the local bus connection to computer communication interface 382, PCI/local bus interface unit 460 functions as a main respondent to commands sent over computer communication bus 302 to DFN 304. PCI/local bus interface unit 460 includes a PCI command interpreter 462, which processes commands from host computer 114. Example commands include loading the event queue into EAB memory 474 in event sequencer unit 470 with data for an upcoming sequence or processing a begin sequence command.

Event sequencer unit 470 houses an event queue in EAB memory 474 and is responsible for decoding and executing event instructions during sequence operation. The event queue is embodied using available on chip EAB memory 474 on EP 374. The event queue in EAB memory 474 is organized byte-wise for most efficient use of memory resources. Sequencing of events and read/write of the event queue in EAB memory 474 is controlled by queue control unit 472. Interpretation of event instructions is performed by event interpreter 476. As event instructions are read out of the event queue during sequence execution, data to be sent out to the various interfaces is transferred by the event interpreter 476 to other units on EP 374 for further processing.

Fiber channel interface 480 is responsible for maintaining communications with image detection interface 376. Data is transmitted by the FC EP transmit unit 484 and received by the EP FC receive unit 486. The status of the link is monitored by the EP FC control unit 482, which notifies host computer 114 if communication is lost or when anomalous conditions occur. Unlike most of EP 374, which runs off of the 36.0 MHz local bus clock, the EP FC transmit unit 484 runs off of the 31.25 MHz fiber channel transmit clock 584. Similarly, the EP FC receive unit 486 runs off of the fiber channel receive clock 585. This asynchronous operation is used in order to effect a rate change between image detection bus 377 and local bus 384. The units within fiber channel interface 480 communicate asynchronously with the remainder of EP 374 using flags for handshaking and double buffered registers.

EP real time bus interface 490 handles requests for changing the state of real time bus 379 from the event queue in EAB memory 474. EP real time bus interface 490 is also responsible for notifying the event queue and host computer 114 when external devices (e.g. radiation generation system 109) force the state of real time bus 379.

There are two global clock inputs to EP 374, namely GCLK1 input 492 and GCLK2 input 494. These inputs are optimally distributed to all logic on the devices using two dedicated clock trees. On EP 374, GCLK1 492 and GCLK2 494 are driven by the 36.0 MHz local clock 574 and the 31.25 MHz fiber channel transmit clock 584 respectively.

There are also four additional dedicated global signal lines, which are not optimized for timing. On EP 374 these are connected to three reset signal triggers 496. Two reset triggers are generated by computer communication interface 382 (USERo and LCL\_rst), and the third signal comes from a power on reset circuit, set forth in greater detail below.

FIG. 26 is a block diagram of DAP 372, which is the second FPGA to be used in DFN control unit 370. DAP 372 is mainly concerned with accomplishing the rate change between data received from image detection bus 377, effectively

operating at 31.25 MHz, and computer communication bus 302, operating at 36.0 MHz. DAP 372 performs the rate change by storing data received from image detection bus 377 in one frame buffer memory unit 381, while simultaneously reading previously stored data out of a second frame buffer memory unit 381 to computer communication bus 302 through computer communication interface 382.

As illustrated in FIG. 26, DAP 372 is comprised of a number of sub units, which are responsible for orchestrating the flow of image data on DFN 304. Starting with the DAP FC receive unit 500, 32 bit image data is received at the 31.25 MHz fiber channel receive clock rate. Each 32 bit word comprises two 16 bit pixel values, each read out in parallel by detector control board 124. The combined 32 bit word is written into DAP first in first out ("FIFO") unit 502 using the fiber channel receive clock. At the same time, data is being read asynchronously out of DAP FIFO unit 502 and into the pixel reorder unit 504. The reorder function performed by pixel reorder unit 504 is set forth in greater detail below. This data is now processed at the 36.0 MHz local bus clock rate. From the pixel reorder unit, pixels move to crossbar 506, which routes the pixels to the currently active frame buffer memory unit 381.

At the same time that receive data is being stored in the currently active receive frame buffer memory unit 381, previously stored image data is being read out of the currently active stored frame buffer memory unit 381 to computer communication bus 302. Data is again routed through cross bar 506, but this time is passed on to computer communication interface 382, then to computer communication bus 302. The five available frame buffer memory units 381 in DFN 304 each provide an incremental timing safe guard against the possibility of dropping communication on computer communication bus 302. If communication is interrupted, the receive circuitry continues to store the incoming data from image detection system 112, which might otherwise be lost. Once computer communication bus 302 is picked up again, transfer of data continues at the local bus clock rate of 36.0 MHz. This provides uninterrupted data transfer and rate translation between image detection bus 377 and computer communication bus 302.



As part of the data flow architecture, DAP 372 also contains a local bus arbitrator 507, which is responsible for coordinating access to local bus 384 between EP 374, computer communication interface 382 and DAP 372. The connection between crossbar 506 and computer communication interface 382 is in fact bi-directional. This bi-directionality, combined with control of address generator 512 directly by computer communication bus 302 allows host computer 114 to read/write the frame buffer memory units 381 directly.

As illustrated in FIG. 26, DAP 372 is responsible for controlling the address bus and read/write signals for the frame buffer memory units 381. Image frame controller 508 is configured with the details of the type of detector panel being accessed (line length, lines/image) and keeps track of the incoming pixel data to ensure that proper framing is maintained. In the event of inconsistent line length or frame size, an error is generated and reported to host computer 114. Line reorder unit 510 feeds into address generator 512 to generate proper addresses for the currently active receive and store frame buffer memory units 381. At the same time, precise timing of the various memory unit control signals is maintained by the read/write cycle control unit 514. Detailed information regarding frame buffer memory units 381 is set forth below.

There are two global clock inputs to DAP 372, GCLK1 516 and GCLK2 518. These inputs are optimally distributed to all logic on the devices using two dedicated clock trees. On DAP 372, GCLK1 516 and GCLK2 518 are driven by 36.0 MHz local bus clock and the 31.25 MHz fiber channel receive clock, respectively. There are also four additional dedicated global signal lines. On DAP 372 the dedicated global signal lines are connected to three reset triggers 520. Two of the reset triggers are generated by computer communication interface 382 (USERo and LCL\_rst) and the third signal is generated from a power on reset circuit, set forth in greater detail below.

DAP control unit 521 is responsible for overseeing operation of DAP 372. DAP control unit 521 maintains control registers 524 which parameterize the

various operations taking place in the DAP 372. DAP control unit 521 also maintains error registers 522, which are used to report any problems in execution to host computer 114. RAM BIST 528 performs a built in self test of the frame buffer memory units 381 on initial power up and during normal operation on command from host computer 114. Detailed information is set forth below.

FIG. 27 is a block diagram of DFN control unit 370 in conjunction with power on reset unit 535. To facilitate test and debug, as well as for firmware updates in the field, DAP 372 and EP 374 are configurable through programmable memory unit 329. Programmable memory unit 329 includes DAP eeprom unit 532 and EP eeprom unit 530. Alternatively, DAP 372 and EP 374 are programmable JTAG ports JTAG1 542 and JTAG2 544. In typical operation, power is applied to DFN 304 when host computer 114 is first turned on. At this stage each of DAP 372 and EP 374 boot from their respective eeproms and therefore become operational by loading the data from the respective eeprom. FIG. 27 illustrates configuration circuitry on DFN 304. Each of DAP 372 and EP 374 has an associated eeprom unit comprised of two EPC2 chips that are daisy-chained to provide storage for programming. One eeprom unit per each of DAP 372 and EP 374 is shown for simplicity. Each EPC2 chip is a socketed 20 pin PLCC package, which is easily removed for reprogramming. As illustrated, configuration, i.e. loading data, is in passive serial mode in which a single line provides serial data to configure the devices.

The programmable control unit 529 stores initial boot sequence instructions for controlling the detector framing node control unit 370. The programmable control unit 529 loads the initial boot sequence instructions for execution by control unit 570 upon reset or initial application of power to detector framing node 304. According to an embodiment of the present invention, the initial boot sequence instructions are updated by communicating update instructions from host computer 114 through the computer communication interface 382 and into detector framing node memory unit 380. The update instructions are then communicated from detector framing node memory unit 380 to the programmable

memory unit 529. The JTAG loop 545 communicates the update instructions from local bus 384 and programmable memory unit 529.

As illustrated in FIG. 27, DAP power on reset ("POR") unit 536 and EP POR unit 534 are used to hold a reconfig line low for an additional 140 msec after power comes up on DFN 304 and configuration is complete. This ensures that DAP 372 and EP 374 configure in case the power supply rise time of 100 msec is violated. Alternatively, a push button switch is used to force a manual override of each POR circuit and reconfigure the FPGAs without cycling power to the board. All signal lines involved with FPGA configuration are made available on the top layer of the board to facilitate debug of FPGA configuration if a problem is detected during initial test of the board. In addition, jumpers are provided to selectively disable reboot of DAP 372 or EP 374 in order to help debug problems during configuration or due to specific devices.

During test and debug of DFN 304, configuration of the FPGAs and programming of eeprom units 530 and 532 are accomplished through the illustrated JTAG ports 542 and 544. JTAG1 542 is provided for the loop including EP 374 and DAP 372. No-populate 0-Ohm resistors are used to allow for either of EP 374 or DAP 372 to be taken out of the loop in case a problem arises during debug or firmware development.

JTAG2 544 is provided for the loop including the two eeprom units 530 and 532, and is used for programming the eeprom units 530 and 532. The eeprom units 530 and 532 are programmable over their respective JTAG ports using a Byte Blaster cable and MaxPlusII software, by Altera, Inc. of San Jose, California. As illustrated in FIG. 27, JTAG2 544 is also provided for second JTAG loop 545, including DAP eeprom unit 532 and EP eeprom unit 530, used to program the EP 374 and DAP 372.

When DFN 304 is in the field, the firmware is optionally updated to a different version. For convenience, these updates are performed directly without opening host computer 114 and swapping eeprom devices for a later revision. The

capability for in-system programming of the eeprom units is supported through respective JTAG ports as mentioned above. DFN 304 allows host computer 114 to access the JTAG1 542 or JTAG2 544 directly over computer communication bus 302 without using the Byte Blaster cable and MaxPlusII software.

5 As illustrated in FIG. 27, second JTAG loop 545, which allows eeprom units 530 and 532 to be programmed from JTAG2 port 544 is also connected to DAP 372 through user I/O pins. Once the board FPGAs configure properly with the old version of the firmware, the eeprom units are reprogrammable using a firmware application resident in DAP 372. Data for the eeprom units is transferred to the frame  
10 buffer memory units 381 over computer communication bus 302. From the frame buffer memory units 381, the data is read out by DAP firmware, serialized, and transferred over the respective JTAG bus along with format and command information.

After DAP 372 has reprogrammed the eeprom units over the  
15 corresponding JTAG bus, DAP 372 issues a JTAG command to cause the eeprom units to automatically reconfigure both of DAP 372 and EP 374. There is one try allowed for reprogramming of the EPC2 chips forming EP eeprom unit 530 and DAP eeprom unit 532. Error checking is used to ensure that the devices have been programmed correctly, however this will not prevent a user from programming the  
20 wrong firmware into the EPC2s. This situation is mitigated using software interlocks and through general precaution. The eeprom units may always be physically replaced on DFN 304.

DFN 304 uses ten 9.4 Megabit SRAMs, grouped into five frame buffer  
memory units 381. Address and data buses for the SRAMs are connected to DAP 372,  
25 which is responsible for control of these devices and for effecting a pixel data reordering algorithm, set forth in greater detail below. Data reordering for each flat panel detector is achieved by writing data from each row of the detector panel into the SRAM in an order such that when the SRAM is read out sequentially, the data is reordered for correct display on a memory mapped high resolution display 338. The

data is transferred from the SRAMs into computer RAM 334 of host computer 114 using computer communication bus 302 for direct memory access ("DMA").

Each SRAM is in a 100 pin thin quad flat pack ("TQFP") packaging. The part is organized as 256K x 36 and has a 12 nsec cycle time. Address, data inputs, and all control signals, except output enable and linear burst enable, are true on the rising edge of the clock. Operation of the SRAMs are at 36 MHz, which allows head room. Since the data is typically two 16 bit words, the low order 4 bits of each SRAM are unused and the effective memory capacity is 8.4 Mbits. The TQFP package allows debug since all pins are available for probing. However, the use of a BGA package improves manufacturing yield. Five SRAMs are placed on each physical side of the board on which DFN 304 is formed to minimize address and data line length. Pairs of SRAMs forming each frame buffer memory unit 381 are placed on alternate sides of the physical board.

Writing data to frame buffer memory unit 381, formed as a pair of SRAMs, and reading data from a second frame buffer memory unit 381, also a pair of SRAMs, occurs in parallel. This is achieved by providing five 32 bit data buses and five 18 bit address buses in DAP 372, which address and read or write data to the five pairs of 8.4 Mbit SRAMs. Thus, 250 pins of the 600 pin DAP 372 are used for address and data for the SRAMs.

In addition to the 18 bit address bus and the 32 bit data bus, the SRAM control pins used are write enable (WE#), three chip selects (CS1#, CS2, CS2#) and sleep mode (ZZ). CS1# is used to select SRAMs for read or write. CS2 and CS2# are used to implement the data reordering scheme set forth below for the cardiac/surgical digital x-ray flat panel and the radiography digital x-ray flat panel. Sleep mode may be used for power down. Note that the # indicates the pin is active low.

FIG. 28 is a schematic diagram of data being read out of a cardiac/surgical digital x-ray panel 182. As illustrated, first cardiac scan line 185 is the line of data being read out of first panel portion 184, and second cardiac scan line 187 is the line of data being read out of second panel portion 186. Each scan line 185 and

187 is moving in a direction toward the center between split panels 184 and 186. The data is read out of each of the split panels by reading out pixels from the top row of the top panel and the bottom row of the bottom panel in parallel. The data from the first four pixels (two from the top row and two from the bottom row), are stored in the DAP 372 in preparation for writing data into the active frame buffer memory unit 381.

In the case of cardiac/surgical digital x-ray, the data being read out of the cardiac/surgical digital x-ray panel 182 is being stored in SRAMs A1 and A2 of DFN memory unit 380 in DFN 304. SRAMs A1 and A2 comprise a single frame buffer memory unit 381. FIG. 28 represents the correspondence of SRAMs to the data actually being read out, namely into 2 SRAMs. DFN memory unit 380 has 10 SRAMs.

FIG. 29 is a schematic diagram of data being read out of a radiography digital x-ray panel 228. As illustrated, first radiography scan line 231 is the line of data being read out of first panel portion 230, and second radiography scan line 233 is the line of data being read out of second panel portion 232. Each scan line 231 and 233 is moving in a direction toward the center line between split panels 230 and 232. In the case of radiography digital x-ray, the data being read out of the radiography digital x-ray panel 228 is being stored in SRAMs A1, B1, C1, D1 and A2, B2, C2, D2 of DFN memory unit 380 in DFN 304. Each respective pair of SRAMs A1 and A2, B1 and B2, C1 and C2, and D1 and D2 comprise a single frame buffer memory unit 381. FIG. 29 represents the correspondence of SRAMs to the data actually being read out, namely into 8 SRAMs. DFN memory unit 380 has 10 SRAMs.

FIG. 30 is a schematic diagram of data being read out of a mammography digital x-ray panel 244. As illustrated, mammography scan line 245 is the line of data being read out of mammography digital x-ray panel 244. Scan line 245 is moving in a downward direction across panel 244. In the case of mammography digital x-ray, the data being read out of panel 244 is being stored in SRAMs A, B, C, D, E, F, G, and H of DFN memory unit 380 in DFN 304. The physical SRAMs are the same as SRAMs A1 and A2, B1 and B2, C1 and C2, and D1 and D2 set forth above.

However, the designation is changed to reflect sequential data storage in the SRAMs of frame buffer memory unit 381. FIG. 30 represents the correspondence of SRAMs to the data actually being read out, namely into 8 SRAMs. DFN memory unit 380 has 10 SRAMs.

FIG. 31 is a schematic diagram of digital radiosopic image data being read into a plurality of SRAMs A1, A2, B1, B2, C1, C2, D1, D2, E1, E2, which form DFN memory unit 380, in a cardiac/surgical application. The data being read into DFN memory unit 380 is the same data as being read out from cardiac/surgical digital x-ray panel 182 in FIG. 28. The plurality of SRAMs are designated as pairs A1, A2; B1, B2; C1, C2; D1, D2; and E1, E2, to denote that each pair of SRAMs is store data simultaneously. As illustrated, as data is read out from cardiac/surgical digital x-ray panel 182, the data is stored in real time into DFN memory unit 380. Because the amount of data used by cardiac/surgical digital x-ray panel 182 is on the order of 2 MBytes, 2 SRAMs, namely SRAM A1 and SRAM A2 are used for each image.

When cardiac/surgical digital x-ray panel 182 is used in a fluoroscopy application, to acquire real time moving images of 30 frames/second, each SRAM pair stores a single frame of the real time moving image. With reference to FIG. 18, each SRAM pair is denoted as a frame buffer memory unit 381. DFN 304 allows one frame buffer memory unit 381 to acquire data simultaneously while a second frame buffer memory unit 381 reads out data. Each SRAM illustrated in FIGS. 31, 32, and 33 has a pin labeled chip select #1, i.e. CS#1, which is used to select a pair of the SRAM chips at any one time.

FIG. 32 is a schematic diagram of digital radiography image data being read into a plurality of SRAMs A1, A2, B1, B2, C1, C2, D1, D2, E1, E2, which form DFN memory unit 380, in a radiography digital x-ray application. The data being read into DFN memory unit 380 is the same data as being read out from radiography digital x-ray panel 228 in FIG. 29. The plurality of SRAMs are designated as pairs A1, A2; B1, B2; C1, C2; D1, D2; and E1, E2, to denote that each SRAM forming a pair is stored with data simultaneously. As illustrated, as data is read out from radiography

digital x-ray panel 228, the data is stored in real time into DFN memory unit 380. Because the amount of data used by radiography digital x-ray panel 228 is on the order of 8 MBytes, 8 SRAMs, namely SRAMs A1, A2, B1, B2, C1, C2, D1, and D2 are used for each image. FIG. 32 illustrates a single radiography digital x-ray image being acquired into DFN memory unit 380, and in particular, the pair of SRAMs B1, B2.

FIG. 33 is a schematic diagram of digital mammography image data being read into a plurality of SRAMs A1, A2, B1, B2, C1, C2, D1, D2, E1, E2, which form DFN memory unit 380, in a mammography digital x-ray application. The data being read into DFN memory unit 380 is the same data as being read out from mammography digital x-ray panel 244 in FIG. 30. The plurality of SRAMs are designated singularly A, B, C, D, E, F, G, H, I, and J, to denote that each SRAM acquires data individually, rather than in pairs. Data is stored in this fashion because the mammography digital x-ray panel 244 is a single panel, rather than a "split panel," as in the other cases set forth above. As data is read out from radiography digital x-ray panel 228, the data is stored in real time into DFN memory unit 380. Because the amount of data used by mammography digital x-ray panel 244 is on the order of 8 MBytes, 8 SRAMs, namely SRAMs A, B, C, D, E, F, G, and H are used for each image. FIG. 33 illustrates a single mammography digital x-ray image being acquired into DFN memory unit 380.

FIG. 34 is a schematic diagram of memory allocation of a single cardiac/surgical digital x-ray image in computer RAM 334. Alternatively, the cardiac/surgical digital x-ray image may be stored in PCI RAM card 336. Once in computer controlled memory, the digital x-ray image may be processed and viewed under control of host computer 114.

FIG. 35 is a schematic diagram of memory allocation of a single radiography digital x-ray image in computer RAM 334. Alternatively, the radiography digital x-ray image may be stored in PCI RAM card 336. Once in computer controlled



memory, the digital x-ray image may be processed and viewed under the control of host computer 114.

FIG. 36 is a schematic diagram of memory allocation of a single mammography digital x-ray image in computer RAM 334. Alternatively, the mammography digital x-ray image may be stored in PCI RAM card 336. Once in computer controlled memory, the digital x-ray image may be processed and viewed under the control of host computer 114.

FIGS. 31-33 illustrate data being written into DFN memory unit 380. In general, during initial readout from a flat panel detector, the first two pixels from the top row of the flat panel detector are written to the top left most SRAM A1 by pulling the corresponding chip select control pin line CS2# line low. An address line trigger A18 (not shown), which is controlled by firmware on DFN 304, is low on this write cycle. The first two pixels from the bottom row from the flat panel detector are next stored in bottom left most SRAM A2 by pulling a CS2 line high. Address line trigger A18 is high on this write cycle. In practice, two 16 bit pixels, initially from the top row of the flat panel detector are written as a single 32 bit long word in SRAM A1. Likewise, two 16 bit pixels, initially from the bottom row of the flat panel detector are written as a single 32 bit word in SRAM A2.

Data readout from the flat panel detector continues in the above fashion, such that pixel pairs from the top of the flat panel detector are alternately transmitted with respect to pixel pairs from the bottom flat panel across image detection bus. When the SRAM A1 and SRAM A2 are full, data is then stored in SRAM B1 and SRAM B2, and so on. By way of example, for image acquisition from cardiac/surgical digital x-ray panel 182, when SRAM A1 and SRAM A2 are full, the top of the image is stored in SRAM A1 and the bottom of the image is stored in SRAM A2. Data is then stored in the next pair of SRAMs, namely SRAM B1 and SRAM B2. Data is sequentially read out from the SRAMs to accomplish the reordering in traditional left-to-right fashion, such that data is first read out

sequentially from SRAM A1, and then sequentially read out from SRAM A2. Upon readout, the data has been reformatted for display on a monitor.

A pair of SRAMs hold 2 MBytes of data, which corresponds to a single cardiac/surgical digital x-ray image. For radiography digital x-ray, the image is stored in 4 pairs of memory chips, i.e. 8 MBytes of data. Each pair of SRAM memory chips is viewed as storing a 2 MByte stripe of data from the panel. As a pair of SRAM memory chips fill with data, they are available to be readout over PCI bus 383. A portion of an entire image frame output from a flat panel detector may be stored on DFN 304 while another portion is being transferred to host computer 114. Thus, 4048 x 4048 or larger panels are supported.

In a configuration for mammography digital x-ray having a single flat panel, no reordering is provided. Data is read out from the single flat panel in sequential pixel order, two bits at a time, and likewise written sequentially to SRAMs A1, A2, B1, ..., etc. The firmware in DAP 372 handles mammography digital x-ray without reordering.

As set forth above, digital x-ray image data does not go directly from each flat panel detector into SRAM memory, but rather goes through ARC chips 196 and through DRC chip 198 (see FIG. 9), is converted to a serial format on detector control board 124, and is transmitted over image detection bus 377 serially to DFN 304, for conversion back to a 32 bit parallel word. The fiber channel clock is set at 31.25 MHz and the 32 bit words are stored in a DAP 372 register at this rate. One 32 bit word contains two 16 bit pixels, one from the top panel of a split panel detector and one from the bottom panel, for cardiac/surgical and radiography digital x-ray. Data is written to or read from memory using the 36 MHz clock of computer communication bus 302. The data transfer over computer communication bus 302 occurs at the 33 MHz clock rate of computer communication bus 302. The buffering used to convert the clock rate from image detection bus 377 to local bus 384 to computer communication bus 302 occurs within FIFOs on computer communication interface 382 or optionally in DAP 372.

FIG. 37 is a schematic view of computer communication interface 382, which is a 32 bit, 33 MHz PCI bus master I/O accelerator chip. Computer communication interface 382 implements PCI class specifications and operates in burst mode at transfer rates up to 132 MByte /second. Computer communication interface 382 interfaces with computer communication bus 302 operating at 33 MHz to DFN local bus 384 operating at 36 MHz and above. Internally Computer communication interface 382 contains a first in first out ("FIFO") memory to perform data rate conversion between the two busses. Features of computer communication interface 382 include DMA engines, direct slave and direct master capability, and PCI messaging using mailbox and doorbell registers.

DMA is used to transfer images from 2 MByte memory buffers on DFN 304 directly to computer RAM 334. Using the DMA engines on computer communication interface 382 relieves the burden of managing the data transfer from both the computer application and from the processors on DFN 304. DMA setup has four 32-bit words of data to be written to computer communication interface 382. The 32-bit words of data include a local base address, a PCI base address, a size of transfer, and a command to initiate the transfer. These four 32 bit words are written by EP 374 when a memory buffer needs to be transferred to computer RAM 334.

Direct slave mode of operation is used for all direct computer accesses to DFN 304. Computer communication interface 382 is programmed to recognize the address on computer communication bus 302 where DFN 304 resides. When a memory access within defined memory space of DFN 304 is accessed, computer communication interface 382 responds on computer communication bus 302 and performs a memory access on the local bus side of DFN 304. This mode of operation is used to read and write registers on DAP 372 and EP 374, to access memory within the memory buffers on DFN 304, and to send commands to DFN 304.

Direct master mode of operation is used for sending detector information to host computer 114. When DFN 304 receives an acknowledgement from an issued command, DFN 304 sends this information to a pre-designated buffer

in computer RAM 334. Host computer 114 sets up the buffer space and authorizes DFN 304 to transfer data into computer ram 334 before this mode of communication is used.

Computer communication interface 382 has a number of mailbox registers, and two doorbell registers used for messaging between DFN 304 and the computer application. There is a 32-bit outgoing and a 32-bit incoming doorbell register. The mailbox registers are used to buffer the results of commands to DFN 304. The outgoing doorbell register is used to send interrupts to the host computer 114. Interrupts originate from a number of sources, including command completion signals and errors.

Computer communication interface 382 PCI bus side signals are generally set forth in Table 2 below:

Table 2

Name	Pin Function
AD(31:0)	PCI side multiplexed Address/Data Bus
C_BE(3:0)	PCI side byte enables
DEVSEL	Device Select
ENUM	Enumeration; Hot-swap related
FRAME	Cycle Frame; Defines a frame of data
GNT	Grant; PCI bus granted to card
RST	Reset; PCI reset will reset the computer communication interface 382
IDSEL	Initialization Device Select
INTA	Interrupt A; PCI interrupt request by DFN to computer
IRDY	Initiator Ready
LOCK	Lock; Lock computer communication bus 302
PAR	Parity; Even parity on AD and CBE
PERR	Parity Error; Report data parity errors
PME	Power Management Event
REQ	Request; Request for computer communication bus 302

SERR System Error; Report Address parity errors

STOP Stop; Request to stop current transaction

TRDY Target Ready

PCLK PCI Clock; 33 MHz

5 Table 3 sets forth computer communication interface 382 local bus side signals.

Table 3

	Name	Pin Function
	LBA(31:0)	Local Address Bus
10	LBD(31:0)	Local Data Bus
	ADS	Address Strobe; Indicates start of address cycle
	BIGEND	Big Endian Select; Unused
	BLAST	Burst Last; Indicate last transfer in bus access
	BREQIBus Request In; EP uses the bus	
15	BREQO	Bus Request Out; computer communication interface 382 uses the bus
	BTERM	Burst Terminate
	EOT	End Of Transfer; Terminate current DMA
	DP(3:0)	Data Parity; Unused
	LBE(3:0)	Byte Enables
20	LHOLD	Local Bus Request; Request the bus from local arbitrator
	LHOLDA	Local Bus Grant; Local arbitrator grants the bus
	LSERR	System Error PCI System error interrupt
	LW_R	Local Write/Read; Low for reads
	READY	Ready; Bus Master prepared for transaction
25	L_WAIT	Wait; Inserts wait states
	Table 4 sets forth computer communication interface 382 general signals.	

Table 4

	Name	Pin Function
30	CCS	Config Register Select

LCLK	Local Bus Clock; 36.0 MHz (max = 50 MHz)
LED	Hot-Swap LED, monitor; Unused
LINT	Local Bus Interrupt; Used by EP to interrupt PCI Bus
LRESET	Local Bus Reset; Reset FPGAs on PCI reset
5 MODE(1:0)	Bus mode; Set to "00" = C Mode
USERI	FPGA controllable input signal; Unused
USERO	Computer controllable output signal; software reset and pwrdown mode
TEST	Initiate NANDTREE boundary test; Pulled high for test

FIG. 38 is a block diagram of image detection interface 376. DFN 304 supports image detection interface 376, which is capable of transferring data at a rate of 1.25 Gbps from image detection system 112 to EP 374. This interface is a modification of the fiber channel standard (ANSI standard X3T11), which is widely used in commercial high speed RAID disc arrays products. The system clock rate has increased over the prior IDC system, which uses a real time operating system, from 1.0625 GHz up to 1.25 GHz. This change supports an increased image data transfer rate.

Transmission over image detection bus 377 is divided into a hierarchy of layer abstractions, each handling key aspects of a complete Gbit communications system. However, the physical and transmission protocol layers (FC-0 and FC-1 respectively) are relevant because these layers are the layers that have been implemented by image detection system 112. Electronics in image detection system 112 implement the FC-0 and FC-1 standards using a set of three custom ICs and a fiber optic transceiver module.

FIG. 38 is a block diagram of image detection interface 376 on DFN 304. Image detection interface 376 includes encoder/decoder unit 566, fiber optic transmit unit 562, fiber optic receive unit 564, and fiber optic transceiver 560. Buffer unit 568 is connected to fiber optic transceiver 560 and outputs signal detection signal sig\_det therefrom. The FC-0 layer defines a full duplex serial communications link

operating at 1.0625 GHz. Image detection system 112 deviates slightly from this standard and instead operates at 1.25 GHz.

As illustrated in FIG. 38, the physical layer is comprised of the fiber optic transmit unit 562 chip, fiber optic receive unit 564 and fiber optic transceiver 560. The fiber optic transmit unit 562 accepts a ten bit input at 125 MHz and serializes the input up to a 1.25 GHz transmit rate. The transmitter 562 drives the F/O module over a differential positive emitter-coupled logic ("PECL") interface. Similarly, receiver unit 564 is driven by the PECL outputs of the fiber optic transceiver 560 at the 1.25 GHz rate. The receiver deserializes the input data stream and produces ten bit data at a rate of 125 MHz. The 1.25 GHz transmit clock is generated by fiber optic transmit unit 562 by multiplying a 31.25 MHz reference clock by 40 times using an onboard phase lock loop ("PLL"). Similarly, the deserializer recovers the 1.25 GHz clock from the incoming serial data and divides the 1.25 GHz clock by 40 to generate the 31.25 MHz receive clock.

The fiber channel standard is quite strict concerning the need for precise timing of the reference clock to avoid problems related to jitter noise. A high quality crystal oscillator is therefore used on DFN 304 to ensure a stable a reference clock. Signal integrity for the 1.25 GHz transmit and receive channels is also a potential concern. Transmit and receive chips are placed as close as possible to the fiber optic transceiver module. In addition, these signals are routed on the top layer of the board as micro strip lines to minimize capacitive loading.

The FC-1 layer defines a communications protocol by which packets of data are transmitted and received in 32 bit words at a rate of 31.25 MHz. The FC-1 layer incorporates 8bit/10bit encoding as well as cyclic redundancy check ("CRC") processing to ensure data integrity. This layer is also responsible for establishing and maintaining coherent data communication with the device on the other end of image detection bus 377. Each of these functions is discussed further below.

As shown in FIG. 38, the transmission protocol layer in the fiber channel subsystem is comprised of encoder/decoder unit 566. Encoder/decoder unit

566 interfaces to EP 374 over two independent 32 bit data buses: one for transmit and one for receive. Both the transmit and receive data buses operate at the 31.25 MHz word rate. Encoder/decoder unit 566 takes the input data, performs 8bit/10bit encoding, then outputs ten bit words to the fiber optic transmit unit 562.

5 Encoder/decoder unit 566 also receives ten bit words from fiber optic receive unit 564 and performs reverse 8bit/10bit encoding to output 32 bit receive data to EP 374. In addition to these functions, encoder/decoder unit 566 monitors the state of image detection bus 377 and provides status information to EP 374.

The FC-0 layer transmits and receives data in ten bit words at a rate of 10 125 MHz. These ten bit words are in fact special characters which are mapped to the 8 bit data that is transmitted and received by EP 374. The reason for this 8-bit/10-bit encoding is to mitigate the effects of PLL wander. Each of the ten bit characters contain a number of high to low transitions such that the PLL in the receive circuit continues to accurately recover the 1.25 GHz transmit clock from the incoming serial 15 data. Encoder/decoder unit 566 takes the incoming 32 bit word, parses the word to successive bytes, and then performs 8bit/10bit mapping to generate the output for fiber optic transmit unit 562. Similarly, encoder/decoder unit 566 takes the input from fiber optic receive unit 564, performs decoding, and assembles the resulting bytes into 32 bit words. In addition to the 256 characters that map the 8 bit transmit data, there 20 are a number of utility characters that provide link, framing, and status information. These are discussed in further detail below. In order to further ensure the integrity of the transmitted data, encoder/decoder unit 566 performs CRC processing on the incoming and outgoing 32 bit data.

According to protocol of image detection bus 377, data from EP 374 is 25 transmitted in packets of 4 or more 32 bit words called data frames. Data frames are comprised of data words and special command words called ordered sets. There are typically three types of data frames encountered when communicating with image detection system 112.



FIGS. 33, 34, and 35 are block diagrams of each of three types of data frames. EP 374 and DAP 372 accept and transmit the indicated data frames. An ordered set has a unique 32 bit word defined by a fiber channel standard and is used to communicate specific information to EP 374. Ordered sets are detected by encoder/decoder unit 566 during 8bit/10bit encoding and flagged to EP 374 using the CRXC0 signal line. When this line goes low, the data presented to EP 374 constitutes ordered sets. Image detection system 112 makes use of a handful of the ordered sets which have been defined by the fiber channel standard. Start of data frame is indicated using either SOFn1, SOFn2, or SOFn3 and end of data frame is indicated using EOFn. When not transmitting useful data, the IDLE ordered set is transmitted.

FIG. 39 is a block diagram of command data frame 620, which is the simplest type of data frame used. Command data frame 620 is used to send commands over image detection bus 377 to image detection system 112. Once command data frame 620 is received and processed, an acknowledge is returned. This acknowledge is also in the form of a command data frame. The command data frame begins with an SOFn1 and is followed by two 32 bit data words. The first word, HDR1 defines the type of command transmitted. The second word HDR2 provides the argument for the particular command. The data frame ends with the EOFn ordered set character.

FIG. 40 is a block diagram of image detection data frame 622. Image detection data frame 622 is similar to command data frame 620 but differs in that the start of the data frame character is now SOFn2, and HDR1 and HDR2 are replaced by a series of 32 bit data words comprising pixel value data such that 528 words are transmitted in a single data frame. When the data frame is complete, the EOFn character is transmitted.

FIG. 41 is a block diagram of image done data frame 624. Image done data frame 622 is used to indicate the end of a complete image and is identical to command data frame 582, except for the start of data frame being replaced by SOFn3 instead of SOFn1.

When power is applied to image detection interface 376, the transmitter and receiver chips begin communicating with the system on the other end of image detection bus 377. Before useful data is transferred across the link, however, synchronization is first established between the two systems. The first step in link

5 synchronization is to properly frame the serial data that is being received by fiber optic receive unit 564. After encoder/decoder unit 566 comes out of reset, encoder/decoder unit 566 asserts the SYNCEN line on the fiber optic receive unit 564, which forces search for a special K28.5 fiber channel "comma" character, which is being transmitted by the system on the other end of the link. Once this character is located,

10 the fiber optic receive unit 564 will word align the incoming serial data to the ten bit boundary and notify encoder/decoder unit 566 using the SYNC line.

Encoder/decoder unit 566 will then monitor the incoming 8 bit data words for known framing characters to determine whether proper communication with the other system has been established. Once the link is good, encoder/decoder unit 566

15 will deassert SYNCEN. In the current system, SYNCEN is connected to a WRDSYNC line. The WRDSYNC line is also connected to EP 374 and notifies same that link synchronization has been established.

If during typical operation of image detection bus 377, link synchronization is somehow lost (e.g. image detection bus 377 becomes unplugged),

20 encoder/decoder unit 566 will detect that an anomalous situation exists. In this case, encoder/decoder unit 566 will reassert the WRDSYNC line ("SYNCEN") simultaneously notifying computer 114 that there is a problem and will force the receiver to search for word alignment. Image detection interface 376 will then continue to search for good ten bit characters until synchronization is reestablished.

25 During the time that the system is attempting to achieve synchronization, EP 374 monitors progress on receive status lines. EP 374 also observes unframed data on the receive data bus to look for special data words (such as the IDLE ordered set), which provide status information on the state of image detection bus 377. If synchronization is not achieved, the control block resets

encoder/decoder unit 566 and attempts to lock once more. After two tries if synchronization is not established, an error is reported to computer 114.

Fiber optic transceiver 560 provides media transition for DFN 304 and also outputs a SIGDET signal, which goes low when the receive photo diode in fiber optic transceiver 560 fails to detect optical power for reliable operation. This signal is then output by fiber optic transceiver 560 to buffer 568. This situation typically means that the system on the other side of the link is turned off or the cable of image detection bus 377 has been unplugged. If SIGDET goes low an error is reported to computer 114 so that the operator optionally reconnects the fiber cable or investigates the problem further.

Image detection interface 376 includes a number of control transmit signals set forth in Table 5, setting forth transmit signal assignments below:

Table 5

Name	Pin Function
CTXD0	Transmit data bus
CTXCLK	Transmit clock; 31.25 MHz
CTXC0	Ordered Set; Low=data; high=control word
CTXC1	CRC; Low=check CRC; high=generate CRC
CTXCERR	CRC Error; High=CRC error detected
CTXWREF	Reference word clock
RESETN	Reset Endec; Active low
LOOPEN	Loop Enable; Loop the Transmitter to the Receiver
REFCLK	Reference Clock; Used to lock local PLL
SIGDET	Signal Detect; When low indicates no laser input

Table 6 below sets forth receive signal assignments.

Table 6

Name	Pin Function
CRXD0	Receive data bus

	CRXCLK	Receive clock; Recovered 31.25 MHz clock
	CRXS0	Ordered Set; Low=data; high=control word
	CRXS1	CRC error flag; High indicates CRC error detected
	CRXS2,3	Line Status
5	CRXS4,5	Line State ID bits
	RXERROR	Receive Error; High indicates bad receiver data
	WRDSYNC	Word Synchronization; Low indicates sync acquired

FIG. 42 is a schematic view of a single channel of real time bus interface 378. DFN 304 communicates with the radiation generation system 109 over a GE Medical Systems ("GEMS") standard through real time bus interface 378. This standard includes of a group of full duplex differential signal lines operating at 0 and 5 V levels. There are twelve channels on real time bus 379, with more channels being optionally added. The Institute of Electrical and Electronics Engineers ("IEEE") maintains a standard known as RS-485, which is typically used for high speed SCSI interface products. Real time bus interface 378 implements a subset of IEEE RS-485 and uses transceiver chips which have been designed to meet RS-485. One channel 569 of a RS-485 transceiver for real time bus interface 378 is particularly illustrated. Data is input on the D line and buffered by way of transmit buffer 570 to a differential output on out A and out B. Unlike emitter coupled logic ("ECL"), these outputs have a large signal differential where for example, if out A is 5 V then out B will be 0 V (and visa versa). The output drivers are enabled using the DE line. Data is received by receive buffer 572 driving the R output line, which also effects differential to single-ended conversion. The receiver is disabled using the RE line. Monitoring the driver output with the receiver provides useful redundancy for self test.

Real time bus interface 378 has three RS-485 channels on one device. Individual control of the transmit output enable line is provided while control of the receive output enable line are ganged together on one pin. The part therefore has a three channel input, output and control bus for a total of 9 basic signals, which is routed to EP 374. Each channel is capable of driving 60 mA and operates at up to a 10 MHz (30 nsec pulse). Real time bus interface 378 includes a total of 36 basic signal

lines, which are routed from EP 374 to the transceiver chips to control all 12 channels. Real time bus 379 is made available external to the DFN 304 card using a 31 pin female micro miniature D type connector. Voltage suppressors are also included as part of the real time bus interface 378 to ensure that the transceivers will not be damaged if a connecting cable to radiation generation system 109 is unplugged with power being applied to DFN 304 or when undesired transients are generated by radiation generation system 109.

FIG. 43 is a block diagram of DFN clocking system 582. Clocking system 582 is designed to interface between a number of different modes of communication. In order to accommodate these interfaces, four different clocks are used. Distribution and generation of these clocks is particularly illustrated.

As illustrated in FIG. 43, fiber channel transmit clock provides image detection bus 377 with transmit communication at 31.25 MHz. Fiber channel transmit clock 584 is used as a reference clock for fiber channel receive and transmit circuit PLLs. A crystal oscillator on DFN 304 generates fiber channel transmit clock 584. This clock has a 50% duty cycle with no greater than 10% deviation. The jitter noise on this clock is less than 40 ppm.

Fiber channel transmit clock 584 is buffered using clock buffer 576 and is distributed to image detection bus 377 circuitry as well as to EP 374, DAP 372 and a FC test port (not shown). Fiber channel transmit clock 584 is used in EP 374 to drive the FC transmit logic directly. Clock 384 is routed to one of the two available global clock pins on EP 374. On DAP 372, fiber channel transmit clock 584 is routed to one of the dedicated global input signals.

Fiber channel receive clock 585 is recovered from the incoming fiber channel signal data by a phase lock loop located in fiber optic receive unit 564. This clock has been generated on the other side of image detection bus 377 and is a 31.25 MHz clock that is asynchronous to the 31.25 MHz transmit clock. Fiber channel receive clock 585 is buffered by one of the two clock buffer chips and is then distributed to DAP 372, EP 374 and a FC test port. On DAP 372, fiber channel

receive clock 585 is routed to one of the available global clock inputs. This configuration allows the clock to be used for the on-chip FIFO which facilitates a rate change from image detection bus 377 to local bus 384 for storage of data in DFN memory unit 380.

5                   The local clock 574 is generated using a crystal oscillator on DFN 304 and provides a main clock for all devices interacting through the local bus 384. This clock operates at 36.0 MHz. Computer communication interface 382 operates up to 50 MHz, and therefore sets an upper limit on local bus clock speed. The local bus clock speed is selected to be slightly higher than computer communication bus 302 clock speed to improve PCI bus utilization.

10                   The local clock 574 is buffered by one of the two clock buffer chips and is routed to computer communication interface 382, DAP 372, EP 374 and a local bus test port 577. Local clock 574 is routed to one of the two dedicated clock inputs on DAP 372 and EP 374 for optimum timing performance. In addition to all of the  
15                   local bus devices, this clock is buffered and routed to all of SRAM chips on DFN memory unit 380.

                  PCI clock 587 is generated by a PCI bus arbitrator on computer 114 and is made available to DFN 304 on the PCI card edge connector. This clock is used exclusively by computer communication interface 382 and is not buffered for  
20                   distribution. Each of the above described 31.25 MHz and 36.0 MHz clocks is buffered through one of two clock buffer chips, namely clock buffers 576.

                  FIG. 44 is a block diagram of clock buffer 576. Clock buffer 576 includes two banks of five buffers with separate output enable controls on each. When disabled, the outputs of the clock buffer chips are driven to high impedance. Controls  
25                   for these outputs are routed from the USERo signal, from computer communication interface 382, to disable the local clock 574 through software and from EP 374 to disable the FC clocks through firmware. Local clock 574 is buffered directly through a

driver which cannot be disabled. This configuration allows the chip to operate in standby mode while the rest of the board is unlocked and therefore powered down.

Reset of DAP 372 and EP 374 of DFN 304 into a known state occurs on power up, during debug, and during normal operation if anomalous behavior occurs. Although some devices are designed to boot to a known state on reconfiguration, there is no way to guarantee that this is the desired initial state for proper operation of DFN 304. Moreover, initial reset of DFN 304 over computer communication bus 302 potentially produces undesirable results because DFN 304 will most likely configure well ahead of the computer operating system, and also has control of both image detection system 112 and radiation generation system 109. Thus, on-board reset circuitry is provided to bring DFN 304 to a well defined state. DFN 304 is reset on power-up and through software or hardware as described in this section.

FIG. 45 is a schematic diagram of power on reset system 588. On power-up, DFN 304 is brought to a known state using active circuitry. As illustrated in FIG. 45, a power on reset unit 535 that DAP 372 and EP 374 are held in reset for at least 140 msec after power has stabilized, and such that the FPGAs have been successfully configured (data loaded from eeprom into FPGA memory). The outputs of the FPGA configuration circuitry (EP\_config and DAP\_config) are used to determine that both FPGAs have configured successfully before reset to the devices is released. Reset is held low an additional 140 msec after power has stabilized and both FPGAs have configured successfully. This also ensures that both FPGAs begin functioning simultaneously since they may come out of configuration at different times.

The reset signal from POR unit 535 is routed to DAP 372 and EP 374, and is connected to one of the four dedicated input lines. These dedicated input lines are accessible to all logic on each FPGA device. The firmware is coded for asynchronous reset based on the state of this global input line.

In addition to reset on power-up, DFN 304 resets when a computer reset button is pushed. As shown in FIG. 45, this functionality is provided through computer communication interface 382 using the local bus reset output pin. This pin is held low whenever the PCI RST# line is asserted. When PCI RST# is asserted, computer communication interface 382 resets to a default configuration as specified by PCI eeprom 606. In addition, the reset signal propagates out to all devices on local bus 384 through the local bus reset pin. This signal is routed to EP 374 and DAP 372 and is connected to the second of four available dedicated inputs to these devices. As in power on reset, these global inputs are used for asynchronous reset in the firmware for the two devices. These signals are also logically ORed in firmware with the power on reset signal.

Software (USERo) reset is used for debug of DFN 304 and firmware. Software (USERo) is useful to be able to reset DAP 372 and EP 374 circuitry independent of computer communication interface 382. This capability is provided through the software reset function. Computer communication interface 382 is programmable to change the state of the USERo dedicated line by writing a bit to a register location. As illustrated in FIG. 45, this line is connected to the third available global input line on DAP 372 and EP 374, and is optionally used to reset these devices without resetting computer communication interface 382. The issuing of a "PCI reset" resets both computer communication interface 382 and the FPGAs and is undesirable when attempting to debug a complex problem involving both computer communication interface 382 and the FPGA devices. Additionally, the ability to reset DFN 304 through software directly is useful if anomalous operation occurs. For test and debug on the bench, any of a number of Test Bus signals are used to reset the FPGA devices together or separately. This functionality is coded into the firmware as asynchronous reset on a user I/O pin input signal.

There are three different power supply domains on DFN 304: 5 V, 3.3 V, and 2.5 V. Power for the 5 V devices is taken directly off of the PCI connector. There is one 5 V power plane. The major devices operating off of this supply are the real time bus interface 378 and fiber channel interface 376. The supply is decoupled



using two 10 V 47  $\mu$ F Tantulum and one 0.1  $\mu$ F surface mount capacitors at the connector. Power to the fiber optic transceiver module is decoupled using two pi network type filters in order to prevent extraneous coupling from the module back into the supply. Power for the 3.3 V devices on the card is taken directly off of the PCI connector. There is one 3.3 V power plane. The major devices operating off of this supply are computer communication interface 382, the SRAM Buffer memories, and the two FPGA devices. The supply is decoupled using two 10 V 47  $\mu$ F Tantulum and one 0.1  $\mu$ F surface mount capacitors at the connector. Power for the 2.5 V devices on DFN 304 is generated locally using a 2.5 V regulator. There is one 2.5 V power plane. The major devices operating off of this supply are the FPGAs (core logic). The supply is decoupled using two 10 V 47  $\mu$ F Tantulum capacitors at the output of the regulator. The sense line on the regulator is connected to the 2.5 V power plane near the center of the FPGA devices in order to accurately monitor the supply voltage. For applications using multiple detector framing nodes in a single chassis or for applications having strict power budgets (e.g. a battery operated PC), DFN 304 supports a power down mode of operation.

In reset power down mode, the FPGA and image detection bus 377 devices are held in reset by computer communication interface 382 USERo signal until such time as computer 114 updates this signal using a PCI write to computer communication interface 382. With this method, clock lines to all devices are left toggling, however dynamic logic on these chips is not switching. Computer communication interface 382 does not contribute significantly to the overall power budget on the card. Thus, computer communication interface 382 is left fully operational during power down mode. In clock power down mode, the local bus and fiber channel clocks are disabled by asserting the output enable control lines on the clock buffer chips. There are currently unpopulated jumpers on the board that connect these control lines to the USERo signal from computer communication interface 382. Populating these jumpers selects the clock power down mode as the preferred method for power savings for the card.

In order to verify proper function of key systems on DFN 304, Built In Self Test ("BIST") firmware routines are included. These routines are run automatically on power-up and report any errors detected to computer 114 once communication is established. The tests will also be available to be run through direct commands from computer communication bus 302.

The fiber channel loopback test is designed to test image detection interface 376. The test is initiated by EP 374 by asserting the LOOPEN signal line. This signal line shorts fiber optic transmit unit 562 outputs to fiber optic receive unit 564. This closes the loop through encoder/decoder unit 566 back to EP 374. EP 374 then attempts to send an FC command over the link and monitors the return bus for an expected echo. The format of the command words includes alternating 1 and 0 patterns and is designed to test the transmit and receive bus lines for shorts and opens. If the correct pattern is received, the test passes. The results are reported to computer 114. This test is does not verify the fiber optic transceiver module but is optionally qualified with a setting that causes the test to run without asserting LOOPEN. In this case, a short length of fiber cable is looped from the module output back to its input to close the loop. This test is available for debugging of DFN 304.

The real time bus interface 378 is also tested for integrity of the transceiver chip set electronics. This test is performed by EP 374 by writing data out to the devices on the transmit bus and then monitoring the receive bus for the same data. Since the chips have their receivers and transmitters for each channel wired together, anything transmitted will automatically be received. The test includes a series of words of alternating 1 and 0 patterns which are designed to check for opens and shorts on the transmit and receive data bus traces and chip pins. If this test is successful, it will also show that the chips themselves are functioning correctly. This test is further augmented to test the traces out to a 31 pin miniature D connector as well as the connector solder joints. A special external test connector shorts all even channels to all odd channels. Data is transmitted on the even channels and monitored on the odd channels and visa versa. This test shows that the entire communication

chain out to the connector is working. This test is generally not run automatically and is available for debug of real time bus interface 378.

A RAM Built In Self Test ("BIST") is also provided for DFN 304. DFN memory unit 380 includes ten 8 Megabit SRAM devices, which together  
 5 contribute the majority of connections to DAP 372. There is the possibility that these devices might have been damaged during board handling and therefore they need to be tested using an exhaustive RAM BIST test. RAM BIST includes three related tests, all of which are conducted by firmware in DAP 372. In the first test, odd and even memory locations are filled with alternating 1 and 0 patterns and then read out and  
 10 checked. In the second test the odd and even values are reversed. In the third test, the value of the address of a particular location is written into that location. Once the entire DFN memory unit 380 has been filled, the data is read out and compared to the original. These three tests verify that every bit of SRAM on the card is good and will also check for shorts on traces and between pins on the SRAM chips and on the  
 15 majority of pins on DAP 372.

DFN 304 has built in test and monitoring features. Dedicated test ports, jumpers, test points and temperature monitoring are used for observeability. Test ports facilitate test and debug of DFN 304, and a large number of test points are routed to miniature test ports for direct access. In particular the local bus 384, the internal bus  
 20 connected to image detection bus 377, and the bus that connects DAP 372 and EP 374 have been brought to test ports. Daughter boards, with bus transceivers on them, provide high speed monitoring of signals on these lines without significantly loading them. These buses are used when testing EP 374 and DAP 372, which are FPGA devices and therefore not probed directly. The same is true for computer  
 25 communication interface 382, which is a fineline surface mount part and difficult to probe. Test clips do exist for some of the devices on the board, but dedicated test ports simplify access.

FIG. 46 is a block diagram illustrating chip placement on the physical PCI card 590 of detector framing node 304. Due to the complex electrical layout, and

limited board space available for PCI cards, physical placement of chipset electronics on physical PCI card 590 is considered. Placement of test ports, with respect to other devices on physical PCI card 590 is also incorporated as shown.

As illustrated in FIG. 46, five SRAM chips 600 are placed on a single side of physical PCI card 590. As set forth above, a pair of SRAM chips 600 are used to form each frame buffer memory unit 380 (see FIG. 18). Thus, for each frame buffer memory unit 380, one SRAM chip 600 is placed on a first side of physical PCI card 590, while another SRAM chip 600 is placed on a second side. In this manner, most address and data lines are shared thereby minimizing routing on the physical PCI card 590. Furthermore, DAP eeprom unit 530 is physically comprised of eeprom chips 592 and 594, while EP eeprom unit 532 is comprised of eeprom chips 596 and 598. As illustrated, JTAG1 port 542 and JTAG2 port 544 are physically located on an edge of physical PCI card 590. Real time bus interface 378 is comprised of four interface chips 602 to implement protocol with the real time bus 379 through real time bus connector 604. Computer communication interface 382 is programmed by PCI eeprom 606, which is a separate circuit element. As illustrated, each of fiber optic transmit unit 562 and fiber optic receive unit 564 are separate circuit elements on physical PCI card 590.

Fiber channel test port 610 is placed on physical PCI card 590 for signal monitoring. All fiber channel transmit and receive data bus signals, as well as the status signals and send and receive clocks, are routed to fiber channel test port 610. Local bus test port 612 receives all local data and address bus signals. In addition, all control signals for local bus 384 have been routed to local bus test port 612. DAP/EP/Test port 614 includes a total of 50 lines, including dedicated user I/O pins on DAP 372 and an additional 50 lines on EP 374. The lines from DAP 372 and EP 374 have been tied together and routed to DAP/EP/Test port 614. These signals provide monitoring of signals internal to the FPGA devices. They also constitute an additional dedicated communications bus between DAP 372 and EP for integrating additional functionality.

For convenience in board test, a group of test points are also brought out to be readily accessible. These points are identified in this section. These are isolated points which are not related to the test bus ports, and not particularly illustrated.

5           Temperature monitoring is provided to prevent thermal runaway and for statistical tracking of card operation. Three temperature monitoring devices are incorporated on physical PCI card 590. These devices sit underneath the FPGAs, image detection bus 377 and the SRAM memory buffers. The devices are read over an I2C bus and their outputs are available to computer 114 by way of read out from  
10           temperature monitor registers on DFN 304. Additionally, these devices are monitored directly by the FPGAs themselves at regular intervals. If the temperature is observed to rise above a prescribed limit, DFN 304 is automatically placed in powerdown mode after a temperature overflow error is communicated to computer 114.

          A board revision code is provided on DFN 304 for tracking purposes.  
15           The board revision code is embedded in the physical board artwork. The code includes 8 user I/O pins routed to EP 374 which are either tied high or low directly to yield a revision number. This revision number is then be read directly by computer 114 by interrogating a board revision number register, which is mapped to revision code pins.

          A unique board serial number is also provided for tracking. Every  
20           board produced will have a unique serial number. This serial number is generated using a Si Serial Number IC, by Dallas Semi.: DS2401Z. The serial number IC is interrogated on a single line, which is connected to EP 374. The resulting serial number is stored in a register EP 374, which is readable directly by computer 114.

          FIG. 47 is a block diagram of a mapping 616 of 16 MByte address  
25           space. DFN 304 is included in physical PCI card 590, which in turn is placed in a PCI slot in computer 114. DFN 304 occupies 16 MByte of address pace on PCI buss 302. The PCI controller in computer 114 determines the base address of DFN 304. The 16 MBytes in the PCI address window are organized shown in FIG. 47. Frame buffers A-E are the 2 MByte memories on DFN 304. The location of registers on the EP 374 and

the DAP 372 begin at 24 bit hexadecimal address xA00000 and xB00000, respectively. DFN 304 is controlled by two mechanisms: 1) writing to registers in the EP 374 or DAP 372 or, 2) by sending commands to the EP 374. The registers on the EP 374 and DAP 372 can be accessed by the user program through the acquisition  
 5 DLL 313. EP firmware registers are shown in Table 7 below.

Table 7

	Name	Description
	EP_REV_ID	Current revision level of EP 374
	EP_STATE	Current state of EP state machine (and DFN)
10	DFN_REV	Current revision level of DFN 304
	EAB_SIZE	EAB memory block size in bytes
	RT_BUS	Current state of RTB (state of each bit and direction of each bit)
	STAT05R	RESERVED STATUS REGISTER
15	CUR_QUEUE	Currently executing detector queue command
	LOOP INDEX	Current state of first nested loop index in event queue
	SSN_NUM1	Silicon serial number of DFN board (most significant bytes)
20	SSN_NUM2	Silicon serial number of DFN board (least significant bytes)
	ACK1 HDR1	returned from detector
	ACK2 HDR2	returned from detector
	ERRORQUEUE	Errors relating to queue execution (set by DFN cleared by computer)
25	HOST_FLAGS_REG	Queue register to send interrupts to computer (set by DFN learned by computer)
	ERROR_FC_EP	Fiber channel error register (set by DFN cleared by computer)
30	EP_ENABLE_REG	Enable bit mask for circuits in EP (set by DFN cleared by computer)

	Cmd_0Par	First DFN command parameter
	Cmd_1Par	Second DFN command parameter
	Cmd_2Par	Third DFN command parameter
	Cmd_3Par	Fourth DFN command parameter
5	RT_BUS_CONFIG	Real time buss configuration
	RT_BUS_SER_OUT	Data to be serialized and put out on real time bus serial bit
	HOST_FLAGS_IN	Used to send flags between application and queue
	AUTOSCRUB_DELAY	Autoscrub delay (2 $\mu$ sec intervals)
10	PARAM_BASE	Base address of queue variables in EAB memory
	DBELL_MASK	Specification of which doorbell types are allowed
	LED_STATE	Register to control LEDs on DFN
	CMD_TIMEOUT	Timeout for command executions (2 $\mu$ sec intervals)
	DET_TIMEOUT	Timeout for detector responses (2 $\mu$ sec intervals)
15	WAITF_TIMEOUT	Timeout for wait on flag commands in queue (2 $\mu$ sec intervals)
	DMA_CMD	Used to specify some of the parameters for DMA
	DMA_MODE	Used to specify some of the parameters for DMA
	CMD_REG	Command register (register on EP for commands)

20                   The DAP 372 includes the DAP control unit 521 for maintaining control over the DFN 304 and also has a plurality of error registers for reporting error conditions to host computer 114. Table 8 shows the DAP registers and their accompanying description.

Table 8

25	Name	Description
	DAP_REV_ID	Current revision of the DAP processor FPGA code
	DAP_STATE	Current state of the DAP finite state machine
	RES_LOG_STAT_A	Status register for response log buffer A
	RES_LOG_STAT_B	Status register for response log buffer A

	LAST_WRTN_DFN	Ordinal position pointer of the last buffer written by DFN 304
	DFN_IMG_STAT	Number of images and detector syncs trapped by firmware
5	IMAGE_NUMBER	32 bit image counter
	TIMER_COUNT	2 $\mu$ sec timer counter
	NUM_WRAPS	Number of wraps of timer count
	SEQUENCE_ID	Current sequence (set by computer)
	DAP_STAT0AR	RESERVED STATUS REGISTER
10	DAP_STAT0BR	RESERVED STATUS REGISTER
	DAP_ERRORR	Error register (set by DFN, cleared by computer)
	BIST_ERR BIST	Error register (set by DFN, cleared by computer)
	RES_LOG_FULL	Response log has been filled by DFN (set by DFN cleared by computer)
15	DAP_ENABLE_REG	Enable bit mask for circuits in DAP 372 (set by DFN 304 cleared by host computer 114)
	SIZE_RES_LOG	Response log buffer memory size in computer memory
	BASE_LOG_A	Physical address of response log buffer A in computer memory
20	BASE_LOG_B	Physical address of response log buffer B in computer memory
	TOT_IMG_SIZE	Specifies the size of the detector panel
	NUM_BUFFERS	Number of entries in image buffer list
	IMG_BUF_BAS_ADR	Physical address of image buffer address list
25	END_QUEUE_PTR	End of queue pointer (circular queue of image buffers on computer)
	ROI_ORIGIN	Specifies the upper right hand corner of region of interest
	ROI_SIZE	Specifies the size of region of interest
30	DMA_CHK	Sets window of allowed DMA addresses
	PANEL_SIZE	Specifies the panel size



	GEN_DATA	Specifies the pattern if the system is in generate data mode
	READOUT_SIZE	Specifies the size of the detector panel
	RL_GEN_FLAGS	Flags which enable various response log types
5	DMA_CONFIG	DMA configuration register
	DAP_PARAM15R	RESERVED STATUS REGISTER

Host computer 114 issues a plurality of commands to DFN 304, which are received and interpreted by PCI command interpreter 462 in EP 374. All commands to DFN 304 are executed by writing a 32 bit longword to the single hexadecimal address location xA00200. The command issued is specified by the 8 most significant bits ("MSBs") of the longword. Supported commands are listed in Table 9 below. Each command has up to 24 bits of parameter space to specify operation of the command. Additionally, four registers on DFN 304 are reserved for extra parameter space (command parameter registers). If the command parameter registers are used, these parameters are loaded before command execution. The number of parameters used for a specific command is dependent on the command issued. Each command is described hereinafter.

Upon issuance of a command, DFN 304 will attempt to execute the command. The steps that command interpreter 462 will take are:

1. The command will be decoded and determined if it is a recognized command.
2. The command will be tested for validity depending on the top-level state of DFN 304.
3. The command will be issued to the sub-block on either the DAP or the EP responsible for the function.
4. A command timeout counter will be set and started.

5. Command interpreter 462 will wait until either the executing sub-block executed the command or until the command timeout signal is asserted.

6. The command issued will be copied into mailbox register 0 on computer communication interface 382.

5 7. Results of the command are copied into mailbox registers 1 through 4 on computer communication interface 382.

8. At least one bit in the doorbell register on computer communication interface 382 will be set indicating that the command execution is complete and the DFN 304 can be issued another command.

10 Commands recognized are listed in Table 9 as follows:

Table 9

Command	Description
Get status	Take a snapshot of certain status variables
Run BIST	Execute one or more of the Built in self tests
15 Restart DFN	Issue a soft reset to selected functional blocks
Download EAB memory	Write between 1 and 16 Bytes to the EAB memory
Read back EAB memory	Read between 1 and 16 Bytes of EAB memory
Start queue	Begin executing the detector and x-ray event queues
Abort queue	Abort the execution of detector and x-ray event queues
20 DIAGNOSTIC mode	Make a state transition to top level state DIAGNOSTIC
NORMAL mode	Make a state transition to top level state NORMAL
TEST mode	Make a state transition to top level state TEST
Reset timer	Reset the timer
Abort DMA	Abort currently executing DMA
25 Setup DMA	Setup DMA on DFN 304
Access Local Bus	Perform a read or write on DFN 304s local bus
Send Command	Send a command directly to the detector control board
FC RCV Snapshot	Take a snapshot of the fiber channel receive bus

Switch RL buffer	Switch between response log buffer A and B
Disable Function	Disable one or more explicitly enabled functions of DFN 304
Generate Error	Generate an error to test command processor and driver
5 Host Flag	Computer processor sends a flag to event queue
Unimplemented	A dummy command that will not be implemented in DFN 304 to test the command processor

Each command has a unique command code. They are listed for the individual commands in the tables below. All commands are executed in one or more states of DFN 304.

FIG. 48 is a block diagram depicting the top level states of DFN 304 and the commands available for those states. As illustrated, BIST operation 630 communicates command BIST\_CMP to DIAGNOSTIC operation 632. In turn, DIAGNOSTIC operation 632 communicates bi-directionally with TEST operation 634 and NORMAL operation 638. TEST operation 634 bi-directionally communicates with RUN\_T operation 636 and NORMAL operation 638 communicates bi-directionally with RUN operation 640.

While DFN control unit 370 is executing the above operation, other operations are not issued to DFN 304. When DFN control unit 370 has completed executing the power up sequence, it transitions to a DIAGNOSTIC state. At this time the card will respond to commands. Normally, a command is issued to DFN 304 if the issued command is valid for the current state, such that DFN 304 will execute commands that are valid for that state. If a command is issued to DFN 304 which is not valid for the state that it is currently in, it will respond with an interrupt message indicating that the command was received and understood, but not executed because of a state error. If a command is issued to DFN 304 that is not understood, then DFN 304 responds with an interrupt indicating that a command was received but not understood.

Some commands need to be further specified using one or more of the 24 bits of parameter space argument field and others do not use additional arguments, as set forth below.

5 GET STATUS: TAKE A SNAPSHOT OF ONE OR ALL OF STATUS FUNCTIONS.

Command Code	0000 0001
States where command are executable	DIAGNOSTIC
Parameter Space arguments	bits 2 down to 0
Command Parameter registers	NONE

10 RUN BIST

Command Code	0000 0010
States where command are executable	DIAGNOSTIC
Parameter Space arguments	bits 3 down to 0
Command Parameter registers	NONE

15 RESTART DFN

Command Code	0000 0011
States where command are executable	DIAGNOSTIC
Parameter Space arguments	NONE
Command Parameter registers	NONE

20 DOWNLOAD EAB MEMORY

Command Code	0000 0101
States where command are executable	NORMAL, TEST, RUN, RUN_TEST
Parameter Space arguments	bits 3 down to 0
Command Parameter registers	CMD_0_PAR[,CMD_1_PAR
	CMD_2_PAR CMD_3_PAR]

25

READ BACK EAB MEMORY

	Command Code	0000 0100
	States where command are executable	NORMAL, TEST, RUN, RUN_TEST
	Parameter Space arguments	bits 2 down to 0
	Command Parameter registers	NONE
5	START QUEUE	
	Command Code	0000 0110
	States where command are executable	NORMAL, TEST
	Parameter Space arguments	bit 23 down to 0
	Command Parameter registers	NONE
10	ABORT QUEUE	
	Command Code	0000 0111
	States where command are executable	NORMAL, TEST, RUN, RUN_TEST
	Parameter Space arguments	NONE
	Command Parameter registers	NONE
15	DIAGNOSTIC MODE	
	Command Code	0000 1000
	States where command are executable	NORMAL, TEST
	Parameter Space arguments	NONE
	Command Parameter registers	NONE
20	NORMAL MODE	
	Command Code	0000 1001
	States where command are executable	DIAGNOSTIC
	Parameter Space arguments	NONE
	Command Parameter registers	NONE
25	TEST MODE	
	Command Code	0000 1010

	States where command are executable	DIAGNOSTIC
	Parameter Space arguments	NONE
	Command Parameter registers	NONE
	RESET TIMER	
5	Command Code	0000 1011
	States where command are executable	DIAGNOSTIC, NORMAL, TEST
	Parameter Space arguments	bits 23 down to 0
	Command Parameter registers	NONE
	ABORT DMA	
10	Command Code	0000 1100
	States where command are executable	DIAGNOSTIC, NORMAL, TEST
	Parameter Space arguments	NONE
	Command Parameter registers	NONE
	SETUP DMA	
15	Command Code	0000 1101
	States where command are executable	DIAGNOSTIC
	Parameter Space arguments	NONE
	Command Parameter registers	CMD_0_PAR, CMD_1_PAR, CMD_2_PAR, CMD_3_PAR
20	ACCESS LOCAL BUS	
	Command Code	0000 1110
	States where command are executable	DIAGNOSTIC
	Parameter Space arguments	bit 23 down to 22
	Command Parameter registers	CMD_0_PAR, [CMD_1_PAR]
25	SEND COMMAND	
	Command Code	0000 1111

States where command are executable

Parameter Space arguments

Command Parameter registers

DIAGNOSTIC

bit 23

CMD\_0\_PAR, CMD\_1\_PAR

## FC RCV SNAPSHOT

5 Command Code

0001 0000

States where command are executable

DIAGNOSTIC

Parameter Space arguments

NONE

Command Parameter registers

NONE

## SWITCH RL BUFFER

10 Command Code

0001 0001

States where command are executable

DIAGNOSTIC, NORMAL, TEST,  
RUN, RUN\_TEST

Parameter Space arguments

NONE

Command Parameter registers

NONE

15 DISABLE FUNCTION

Command Code

0001 0010

States where command are executable

DIAGNOSTIC, NORMAL, TEST,  
RUN, RUN\_TEST

Parameter Space arguments

bits 1 down to 0

20 Command Parameter registers

NONE

## GENERATE ERROR

Command Code

0001 0011

States where command are executable

DIAGNOSTIC, NORMAL, TEST,  
RUN, RUN\_TEST

25 Parameter Space arguments

bit 5 down to 0

Command Parameter registers

NONE

## UNIMPLEMENTED

	Command Code	0001 0100
	States where command are executable	DIAGNOSTIC, NORMAL, TEST, RUN, RUN_TEST
5	Parameter Space arguments	NONE
	Command Parameter registers	NONE

## HOST FLAG

	Command Code	0001 0101
	States where command are executable	NORMAL, RUN
10	Parameter Space arguments	bit 7 down to 0
	Command Parameter registers	NONE

PC buffer management is provided by a plurality of image buffer control registers. The registers on DAP 372 are used for image buffer control, and are set forth in Table 10 below.

## 15 Table 10

Register Name	Description
IMG_BUF_BAS_ADR	Base address of list in PC memory (bits 31 to 0)
NUM_BUFFERS	Number of entries in the list (bits 15 to 0)
END_QUEUE_PTR	Last buffer (ordinal) that the computer has processed. (bits 15 to 0)
20 LAST_WRTN_DFN	Last buffer (ordinal) that DFN 304 has transferred Bit 31 flag to indicate that a wrap has occurred. Bits 15 to 0 ordinal of last frame written by DFN.
DAP_ENABLE_REG	Bit "2" when cleared enables the buffer management 25 circuit (set on power up, and on error)



In the following discussion, the flag bFULL (a bit in LAST\_WRTN\_DFN) indicates that the buffers are full and the flag bAllowWrap (a bit in END\_QUEUE\_PTR) indicates that wrapping is enabled.

The host computer 114 will allocate memory for the frame buffers and manage them. The number of buffers will be dependent on the X-RAY application and on the amount of memory available to host computer 114. The buffers are large enough to contain at least 1 frame of image data. The actual size of the image buffer is dependent on the applications. (i.e. 2 MByte for cardiac/surgical digital x-ray, 8 MBytes for radiography digital x-ray, and 9 MByte for mammography digital x-ray). When the computer wants to capture data, it creates a list of base addresses that are read by DFN 304. This list includes all or a subset of the N buffers that host computer 114 is managing.

For continuous operation, the list will wrap. To indicate whether a wrap has occurred, register LAST\_WRTN\_DFN listed above also has a flag which indicates the occurrence of a wrap. This list is set before the Begin Sequence command or any command where a frame of data will be transferred from DFN 304. The three registers (IMG\_BUF\_BAS\_ADR, NUM\_BUFFERS and END\_QUEUE\_PTR) listed above are initialized before the "begin sequence" command. If the number of entries in the list is "N," then the normal setting for register END\_QUEUE\_PTR will be "N" indicating that all buffers from 1 to N-1 are free to be used by DFN 304.

The DFN initializes bFull=FALSE and LAST\_WRTN\_DFN=0, and the driver initializes END\_QUEUE\_PTR=0. Before acquisition, the Driver sets a "END\_QUEUE\_PTR" bit to 0 (no wrap) or 1 (wrap).

For the operations below, that flag bit is called "bAllowWrap".

By way of example, when the DFN 304 determines that an image is in the DFN memory and needs to be transferred to the host computer 114, DFN 304 executes the following operations:

```

1.    if (bAllowWrap = TRUE)
5      if (LAST_WRTN_DFN = END_QUEUE_PTR)
        if (bFull = TRUE)
            ERROR and stop
        else /* bAllowWrap = FALSE */
            if (LAST_WRTN_DFN = 0)
10         if (bFull = TRUE)
            ERROR and stop
2.    do DMA
3.    increment LAST_WRTN_DFN (modulo)
4.    if (bAllowWrap = TRUE)
15     if (LAST_WRTN_DFN = END_QUEUE_PTR)
        bFull = TRUE
    else /* bAllowWrap = FALSE */
        if (LAST_WRTN_DFN = 0)
            bFull = TRUE
20 5.    send DMA done interrupt to PC
6.    return

```

Host computer 114 will map, then unmap the image(s) and update END\_QUEUE\_PTR. The firmware takes this action whenever END\_QUEUE\_PTR is written by host computer 114:

```

25    if (bAllowWrap = TRUE)
        write to END_QUEUE_PTR sets bFull = FALSE
    else /* bAllowWrap = FALSE */
        write to END_QUEUE_PTR does nothing to bFull

```

The host computer 114 processes and displays frames after DFN 304 has transferred data into them. If host computer 114 is waiting for a frame to be filled by DFN 304, host computer 114 does not need to continuously poll DFN 304. The doorbell message from DFN 304 optionally indicates that DFN 304 has filled a buffer because there may be more types of doorbell messages. The doorbell is set after the whole image has been transferred, not after each DMA transfer, if more than one DMA is performed to transfer the entire image. After the doorbell message has been received, the host computer 114 reads DFN 304 last buffer count (register 3). If the buffer that it wants to process has been filled, it processes and displays that buffer. After host computer 114 is finished processing the buffer, and it is authorizing wraps, it increments the number in the "host last buffer" count (register 4). Upon error in DFN 304, the buffer management circuit disables itself by setting bit "2" in the DAP\_ENABLE\_REG register. The error condition identified that disables the buffer management circuit occurs when DFN 304 has a image buffer using transfer to host computer 114, such that  $DFN\ 304\ reads\ if\ VAL(register\ 4) = (VAL(register\ 3) + 1) \bmod N$ .

The response log acquires image data information. According to an embodiment of the present invention, the image data information includes commands and errors as they occur such that the image data information can be associated with a corresponding captured image. For response log management, response log packets are sent to host computer 114 as they are generated on DFN 304. A command sent to the detector while executing the event queue generates a response log packet if enabled. Any command sent to the detector is enabled or disabled from generating a response log packet.

#### Definition of Response Log ("RL") Entry Format

The format incorporates a unique Type identifier for each response log ("RL") entry. This format is to make it easier for applications to sift through RL data for particular types of information. The Type identifier is divided into Class and Subclass sections and includes 4 bits that are reserved for chaining. Chaining is used

to create a single RL entry with up to 128 Bytes of data available. The RL entry format includes a 32 bit time stamp which is the elapsed time since the beginning of the sequence. The Sequence ID has a 24 bit unique identifier which is written by a DFN driver using the either the Begin Sequence command or the Reset Timer command; DFN mode reflects the current mode of operation of the card (e.g. Diagnostic, Run, etc...). There are five 32 bit fields which store the data for the entry. Their use is defined depending on the type of the response log entry. A predefined separator to make it easier to sift through a corrupted RL buffer terminates the structure. A response log entry is organized in little Endian format; that is the least significant byte of a field or object occupies the lower address in the response log 737 (FIG. 61). For example, the response log entry will begin with the Type field bits 7:0, the subclass and reserved chaining information.

Table 11 below sets forth a structure of the response log ("RL") entry format.

Table 11

Object	Bytes	Description
Type	2	Class(7:0); subclass(11:8)
Timestamp	4	Time when data generated
Sequence ID	4	Unique identifier(23:0); DFN mode(27:24)
Field 1	4	32 bit Data Word 1
Field 2	4	32 bit Data Word 2
Field 3	4	32 bit Data Word 3
Field 4	4	32 bit Data Word 4
Field 5	4	32 bit Data Word 5
Terminator	2	Separator word ("0xFAFA")

#### Classes of Response Log ("RL") Entry

A number of specific classes of RL entry are defined to make it easier to sort through the data when looking for particular information. Currently defined

classes are shown in the Table 12 and discussed in this section. RL entry reporting for class 0x03 is individually disabled using a bit field in the respective event code. Reporting for classes 0x02, 0x04, and 0x06 is individually disabled using bits in registers on DFN 304. The class field "-S-" is a 4 bit Subclass place holder; the class field "-N-" is a 4 bit place holder reserved for chaining of RL entries.

Table 12 sets forth currently defined RL entry classes.

Table 12

	CLASS	CLASS CODE	Sub-class
	Image Tag	0x01	-x0
10	Detector Command	0x02	-x0,x1,x2
	Queue Event	0x03	-x0
	Image Readout	0x04	-x0,x1
	Real time bus State	0x05	-x0
	DMA Information	0x06	-x0
15	Sequence Transition	0x07	-x0,x1,x2,x3
	Error	0x0E	-x0

#### Image Tag

An image tag is generated when the end of frame (SOFn3) is received on the image detection bus 377 for the respective image. The tag records the exact time at the end beginning of the frame sequence in ticks of the 2  $\mu$ sec Frame Sequence counter. It also records the Ordinal Image Number for the particular frame. In addition, it records the image specific register settings which were active when the image data was received. This setting includes the image and block size as well as any additional frame options that control readout of the image. This entry also records data read from the SOFn3 which provides details on the formatting of the image data from the detector.

Table 13 below sets forth a format of image tag RL entry.

Table 13

	Object	Description	Format
	Identifier	Image Tag	Class(7:0)= 0x01, subclass(11:8) = 0x0
	Timestamp	Time data generated	32 bit count in 2 $\mu$ sec clk tics
5	Sequence ID	Unique identifier	RESERVED(31:28), DFN Mode(27:24); Sequence ID(23:0)
	Field 1	Ordinal Image #	32 bit count of current image
	Field 2	Image Size	-
	Field 3	Block Size	-
10	Field 4	SOFn3 – HDR1	(B3: Number of bits per pixel)
	Field 5	SOFn3 – HDR2	(B0-1: Pixels per line) (B2-3: Lines per image)
	Terminator	Unique separator	0xFAFA

## Detector Commands

- 15                    Detector Command RL entry is generated when a command is sent and executed on the detector. The entry is not generated until either the acknowledgment is received from the detector or the fiber channel timeout is exceeded. The entry contains the original command, and the detector response. RL entries are also created for spontaneous detector acknowledgment without DFN initiation for debugging
- 20                    purposes. In this case, fields 1 and 2 will be 0xFFFFFFFF indicating an anomalous condition and Fields 3 and 4 will hold the detector response.

Table 14 sets forth a format of detector command RL Entry.

Table 14

	Object	Description	Format
25	Identifier	Detector Command	Class(7:0)= 0x02 subclass(11:8) = 0x0 : normal 0x1 : Unexpected detector ack received 0x2 : Timeout: Detector did not respond

Timestamp	Time data generated	32 bit count in 2 $\mu$ sec clk tics
Sequence ID	Unique identifier	RESERVED(31:28) DFN Mode(27:24); Sequence ID(23:0)
Field 1	CMD - HDR1	Type of Detector command
Field 2	CMD - HDR2	Argument of command
Field 3	ACK - HDR1	Detector response - type
Field 4	ACK - HDR2	Detector response - argument
Field 5	Reserved	-
Terminator	Unique separator	0xFAFA

#### 10 Event Queue Information

The Event Queue RL entry is generated whenever a Detector queue event is executed. The entry contains an Event Descriptor which gives the byte code for the event type as well as the current value of the queue pointer into EAB memory for the respective event instruction. The arguments of the event instruction are stored in Fields 2 and 3. Additional information, like the current value of the loop pointer on a Loop instruction is stored in Field 4. Loop entries generate an entry each time through the loop.

Table 15 sets forth a format of event queue response log ("RL") entry.

Table 15

20	Object Identifier	Description Queue Event	Format Class(7:0)= 0x03 subclass(11:8) = 0x0
	Timestamp	Time when data generated	32 bit count in 2 $\mu$ sec clk tics
	Sequence ID	Unique identifier	RESERVED(31:28) DFN Mode(27:24); Sequence ID(23:0)
25	Field 1	Event Descriptor	Event Byte code(7:0); Queue Pointer(15:8)

	Field 2	Event Arguments 1	Event arguments B0(7:0); B1(15:8); B2(23:16); B3(31:24)
	Field 3	Event Arguments 2	Event arguments B4(7:0); B5(15:8); B6(23:16); B7(31:24)
5	Field 4	Ancillary Information	Loop event: Current value of the loop counters loop2_index(31:16); loop1_index(15: 0)
	Field 5	Reserved	-
10	Terminator	Unique separator	0xFAFA
		Image Readout Information	

Image readout related information is recorded using these RL entries. This information is embedded in the data received from the detector during image readout and is used for debugging detector readout firmware. This data corresponds to the SOFn2 and SOFn3 commands received during image acquisition. Data for the SOFn1 command is stored in the image tag and discussed above.

Table 16 sets forth a format of image readout RL entry.

Table 16

	Object	Description	Format
20	Identifier	Image Readout	Class(7:0)= 0x04 subclass(11:8) = 0x0 : Image Packet (SOFn2) 0x1 : Image Done (SOFn3)
	Timestamp	Time data generated	32 bit count in 2 $\mu$ sec clk tics
25	Sequence ID	Unique identifier	RESERVED(31:28) DFN Mode(27:24); Sequence ID(23:0)
	Field 1	Line number	Hdr11 (Image Packet)
	Field 2	Reserved	-



Field 3	Reserved	-
Field 4	Reserved	-
Field 5	Reserved	-
Terminator	Unique separator	0xFAFA

## 5 Real Time Bus State

The Real Time Bus State RL entry is generated when a state change is detected on real time bus 379. This information will be useful for tracking the actual state of the lines of real time bus 379 during acquisition.

Table 17 sets forth a format of real time bus state RL entry.

## 10 Table 17

Object	Description	Format
Identifier	Real Time Bus State	Class(7:0)= 0x05 subclass(11:8) = 0x0
Timestamp	Time data generated	32 bit count in 2 $\mu$ sec clk tics
15 Sequence ID	Unique identifier	RESERVED(31:28) DFN Mode(27:24); Sequence ID(23:0)
Field 1	New State	RESERVED(31:28) State after the change: Read state(11:0); Drive state (27:16)
20 Field 2	Previous State	RESERVED(31:28) State before the change: Read state(11:0); Drive state (27:16)
Field 3	Reserved	-
Field 4	Reserved	-
25 Field 5	Reserved	-
Terminator	Unique separator	0xFAFA

## DMA Information

The DMA Information RL entry is generated when DMA of the current image buffer is initiated. This information will be useful for debugging DMA problems including situations in which third party PCI cards are reducing the available bandwidth on the bus.

5 Table 18 sets forth a format of DMA RL entry.

Table 18

Object	Description	Format
Identifier	DMA Information	Class(7:0)= 0x06 subclass(11:8) = 0x0
10 Timestamp	Time data generated	32 bit count in 2 $\mu$ sec clk tics
Sequence ID	Unique identifier	RESERVED(31:28) DFN Mode(27:24); Sequence ID(23:0)
Field 1	Image Number	Ordinal image number (31:0)
Field 2	Current Buffer	Ordinal buffer number (31:16); Current 15 DFN buffer number (15:0)
Field 3	Buffer Address	Address of current buffer in computer RAM
Field 4	DMA Size	Size of the DMA packet (31:0)
Field 5	Reserved	-
20 Terminator	Unique separator	0xFAFA

#### Sequence Transition

25 The Sequence Transition RL entry is generated whenever a sequence related transition takes place. Note that the sequence timer is reset whenever an RL entry of this type is generated. When the user mode program begins interaction with the detector outside of an event sequence ("Chit-Chat" mode), the driver resets the sequence timer and passes a sequence ID to DFN 304 to be used for subsequent RL entries. The archive DLL is responsible for keeping track of the absolute time in the system as all RL entries supply relative timing information.

Table 19 sets forth a format of sequence transition RL entry.

Table 19

	Object Identifier	Description	Format
			Sequence Transition
5			Class(7:0)= 0x07
			subclass(11:8) = 0x0
			0x0 : Begin Sequence
			0x1 : End Sequence
			0x2 : Sequence Timer Wrapped
10	Timestamp	Time data generated	0x3 : Sequence Timer Reset
			32 bit count in 2 $\mu$ sec clk tics
			RESERVED(31:28)
			DFN Mode(27:24); Sequence ID(23:0)
15	Field 1	Last Timer Count	State of the sequence timer when transition occurred (31:0)
	Field 2	Wraps since reset	Number of wraps (15:0)
	Field 3	Reserved	-
	Field 4	Reserved	-
	Field 5	Reserved	-
	Terminator	Unique separator	0xFAFA
20	Errors		

The Error RL entry records errors which were generated due to problems on DFN 304 or on the fiber channel link.

Table 20 sets forth a format of error RL entry.

Table 20

25	Object Identifier	Description	Format
			Error
			Class(7:0)= 0x0E
			subclass(11:8) = 0x0

Timestamp	Time data generated	32 bit count in 2 $\mu$ sec clk tics
Sequence ID	Unique identifier	RESERVED(31:28) DFN Mode(27:24); Sequence ID(23:0)
Field 1	EP Error	32 bit error word
5 Field 2	DAP Error	32 bit error word
Field 3	Queue Error	32 bit error word
Field 4	Fiber Channel Error	32 bit error word
Field 5	Reserved	-
Terminator	Unique separator	0xFAFA

10 Table 21 sets forth registers on DFN 304 used for response log control.

Table 21

Register	Description
SIZE_RES_LOG	Size of response log buffers
15 BASE_LOG_A	Base address of response log buffer A, bits(31-12) are used for base address.
BASE_LOG_B	Base address of response log buffer B, bits(31-12) are used for base address.
20 RES_LOG_FULL	Bit YY indicates that response buffer A is filled. Bit YZ indicates that response buffer B is filled. Bit E1 indicates that both response buffers are full and response log circuit is deactivated.
EP_ENABLE_REG	Bit "Y" when cleared enables the response log circuit (set on power up, and on error)
25 RESP_LOG_STAT_A	Status of response log buffer A bits(31-5) contain last written address. Bit(1) indicates if buffer has any data in it. Cleared when response log circuit Enabled, set when first entry is made. Bit(0) when set indicates that last data were transferred to buffer A.

RESP\_LOG\_STAT\_B      Status of response log buffer B bits(31-5) contain last written address. Bit(1) indicates if buffer has any data in it. Cleared when response log circuit Enabled, set when first entry is made. Bit(0) when set indicates that last data were transferred to buffer B.

DFN 304 is initially (on power up and after an error) disabled from sending response log packets. To enable transfer, host computer 114 configures the response log circuit and then enables the circuit. The computer configures the two response log buffers by writing the size of the response log buffers and the base addresses of the two buffers into the SIZE\_RES\_LOG register the BASE\_LOG\_A register and the BASE\_LOG\_B register. The size of the two response log buffers is identical and is an integral multiple of 32 Bytes. The response log buffers start on a 4K page boundary (i.e. bits 11-0 are 0).

Host computer 114 next enables the response log 737 by clearing bit Y of the EP\_ENABLE\_REG. Upon startup, DFN 304 will use the base address of response buffer A for the first response log entry. The second response log entry will be sent to the base address of response buffer offset by 32 Bytes (10000). Subsequent response log entries will be transferred to the base address of response buffer A offset by 32 (Bytes) times the number of response log entries. When the response buffer A is full (address is beyond BASE\_LOG\_A+SIZE), DFN 304 will set bit YY in the RES\_LOG\_FULL indicating that buffer A is full. Bit ZZ in the doorbell register on the PCI 9054 will also be set, sending an interrupt to the host computer 114. If bit YZ in the RES\_LOG\_FULL register is not set, DFN 304 will then start writing response log entries into response buffer B, starting at the base address and continuing until response log buffer B is filled. When buffer B is filled, DFN 304 will set bit YZ in the RES\_LOG\_FULL indicating that buffer B is full and set bit ZZ of the doorbell register on the PCI 9054 sending another interrupt to the computer. Then DFN 304 will check if bit YY in the RES\_LOG\_FULL register has been cleared. If this bit has been cleared, then DFN 304 will reuse response log buffer A. When DFN 304

switches response log buffers from either A to B or from B to A, it will expect that the response log full flags for the next buffers (either YY or YZ of register RES\_LOG\_FULL) are cleared. An error condition will have occurred if the computer has not cleared the bit. If this error condition occurs, bits YY and YZ and Bit E1 of the RES\_LOG\_FULL register will be set, and DFN 304 will set bit Y of the EP\_ENABLE\_REG register, which will disable and reset the response log circuit. Clearing this bit restarts the response log circuit. If the circuit is restarted, DFN 304 will begin transferring response log entries into the base address of response log buffer A.

Host computer 114 forces a switch between the two response log buffers by issuing the command Switch RL buffer. If this occurs, then DFN 304 will immediately switch between buffers A and B. If the switch is forced while response log buffer A is the current active buffer, then bit YY of the register RES\_LOG\_FULL will be set and a doorbell interrupt will be set to the computer. DFN 304 will begin sending response log entries to the base address of response log buffer B. If bit YZ of RES\_LOG\_FULL is set, then an error has occurred and DFN 304 will set bit Y of the EP\_ENABLE\_REG register, disabling the response log circuit.

At any time the host computer 114 reads the two registers RESP\_LOG\_STAT\_A or RESP\_LOG\_STAT\_B to determine the status of the response log circuit. The contents of these status registers contain address of the last response log entry written to response log buffer A and B respectively. They also contain a flag indicating whether response log buffer A or B was the target of the last response log entry. After a forced switch, they are read to determine the number of response log entries that occurred before the switch. They are read after both response-log buffers are filled to determine which buffer contains the older response log entries.

#### Fiber Channel Loopback

The Fiber channel loopback test is designed to test the Fiber channel chip set. The test is initiated by EP 374 device by asserting the LOOPEN signal line.

This signal line shorts the outputs of the fiber optic transmit unit 562 to the receive inputs of the fiber optic receive unit 564. This closes the loop through the encoder/decoder unit 566 back to EP 374. Next, EP 374 attempts to send a FC command over the link and monitors the return bus for the expected echo. The format of the command words has alternating 1 and 0 patterns and is designed to test the transmit and receive bus lines for shorts and opens. If the correct pattern is received, the test passes. The results are reported to the computer.

This test is incapable of verifying the fiber optic transceiver module but is also qualifiable with a setting that causes the test to run without asserting LOOPEN. In this case, a short length of fiber cable is looped from the module output back to its input to close the loop. The test is generally available for debugging of DFN 304.

#### Real Time Bus loopback

The real time bus 379 is testable for integrity of the transceiver chip set electronics. The real time bus loopback test is performed by EP 374 by writing data out to the devices on the transmit bus and then monitoring the receive bus for the same data. Since the chips have their receivers and transmitters for each channel wired together, anything transmitted will automatically be received. The real time bus loopback test has a series of words of alternating 1 and 0 patterns which are designed to check for opens and shorts on the transmit and receive data bus traces and chip pins. A successful real time bus loopback test indicates that the chips themselves are functioning correctly.

The real time bus loopback test is further augmented to test the traces out to the 31 pin miniature D connector as well as the connector solder joints. An external test connector is made up to short all even channels to all odd channels. Data is then transmitted on the even channels and monitored on the odd channels and vice versa. The real time bus loopback test indicates that the entire communication chain out to the connector is working order and is generally not run automatically. The real time bus loopback test is available for debug of real time bus 379.

## RAM Built In Self Test ("BIST")

DFN 304 has ten 8 Megabit SRAM devices which together contribute the majority of connections to DAP 372. There is the possibility that these devices might have been damaged during board handling and therefore they need to be tested using an exhaustive RAM BIST test.

The RAM BIST has three related tests all of which are conducted by firmware in DAP 372. In the first test, odd and even memory locations are filled with alternating 1 and 0 patterns and then read out and checked. In the second test the odd and even values are reversed. In the third test, the value of the address of a particular location is written into that location. Once the entire RAM has been filled, the data is read out and compared to the original.

These three tests will verify that every bit of RAM on the card is good and will also check for shorts on traces and between pins on the SRAM devices and on the majority of pins on DAP 372.

## Interrupts

DFN 304 supports generation of interrupts but does not respond to interrupts. The procedure for handing interrupts generated by DFN 304 is defined here. Interrupts generated on DFN 304 are not directly issued to the PCI interrupt pin. The computer communication interface 382 is responsible for issuing and clearing the interrupt on computer communication bus 302.

The computer communication interface 382 contains two doorbell registers whose purpose is to generate interrupts on DFN 304 and on computer communication bus 302. The doorbell register used to generate interrupts on computer communication bus 302 is the Local-to-PCI Doorbell Register (L2PDBELL). This register is accessed from the PCI side (i.e. host computer 114) at offset x64 from the computer communication interface 382 base address. The host computer 114 reads this register to determine which doorbell bit was set. DFN 304 sets the doorbell by



writing a 1 to a particular bit. The host computer 114 clears a doorbell bit by writing a "1" to that bit position.

The host computer 114 enables DFN 304 generated interrupts by setting two bits in the Interrupt Control/Status Register (INTSCR) on computer communication interface 382. This register is accessed from the PCI side at offset x68 from the computer communication interface 382 base address. DFN generated interrupts are enabled by setting both bit 8, the PCI Interrupt Enable Bit, and bit 9, the PCI Doorbell Interrupt Enable bit.

The L2PDBELL register is a 32 bit register. A particular type of doorbell denotes a unique interrupt messages. The general method of handling interrupts generated by DFN 304 is:

Read the L2PDBELL register;

Determine the source(s) of the interrupt by examining the bits which generated the interrupt;

Perform action(s);

Clear the source(s) of the interrupt on DFN 304;

Clear the bit in the L2PDBELL register which generated the interrupt;

and

Read back the L2PDBELL register to determine that the PCI interrupt has been cleared.

In some cases, depending on the cause of the interrupt, steps 3 and 4 above may not be used.

The specific bit which each specific interrupt type sets in the L2PDBELL register is shown in the following Table 22.

Table 22

	Cause	Bit in L2PDBELL
	Command received and executed normally	0
	Command received and not understood	1
5	Command received and executed with error	2
	Command received and not executed (wrong state)	3
	Command received and not executed (not implemented)	4
	Command received and executed but timed out	5
	End of queue reached with no images pending	6
10	End of queue reached with images pending	7
	Image transfer to computer complete, others are pending	8
	Image transfer to computer complete and non are pending	9
	Interrupt to computer generated in queue	10
	Queue is waiting on signal from computer	11
15	Response Log buffer has been switched	12
	RESERVED	13
	RESERVED	14
	RESERVED	15
	Error (Read ERROR to determine source)	16
20	Error (Read ERR1R to determine source)	17
	Error (Read ERR2R to determine source)	18
	Error (Read ERR3R to determine source)	19
	Error (Read DAP_ERR0R determine source)	20
	Error (Read DAP_ERR1R determine source)	21
25	Error (Read DAP_ERR2R determine source)	22
	Error (Read DAP_ERR3R determine source)	23
	RESERVED	24
	RESERVED	25
	RESERVED	26
30	RESERVED	27

RESERVED	28
RESERVED	29
RESERVED	30
RESERVED	31

5                   The bits marked "RESERVED" are for future use and will not normally be set by DFN 304. The bits marked "Error" indicate that an error has been trapped in either the DAP or the EP FPGAs on DFN 304. If DFN 304 sets one of these bits, the actual source of the error is determinable by reading the appropriate error register as indicated in Table 22. Under normal circumstances, the error is cleared in  
10 DFN 304 before it is cleared in computer communication interface 382.

The interrupts caused by setting bits 0 through 12 on the L2PDBELL register are interrupts that are generated during normal execution.

#### DAP/EP Interaction

15                   Information that is sent from EP 374 to DAP 372 used for assembly of response logs is communicated to DAP 372 using bits (49:34) of the FPGA bus connecting DAP 372 and EP 374.

20                   The entire set of information that DAP 372 needs to assemble response log entries is communicated once for each 2  $\mu$ sec interval. Much of the information originates from the event queue within EP 374. The data is then serialized out of EP 374 immediately after EP 374 receives the 2  $\mu$ sec pulse. The first word out of the event queue is an instruction word, indicating which response log entries need to be generated corresponding to the current event instruction.

The format of the instruction word is set forth in the following Table 23.

25                   Table 23

Name	Description
bits(15)	Reserved

	bit (14)	Make a Detector Command class response entry flag.
	bits(13:10)	Detector Command sub-class code
	bit(9)	Make a Event Queue Information class response entry flag.
	bits(8 : 5)	Event Queue Information sub-class code
5	bit(4)	Real Time Bus State class response entry flag
	bits(3:0)	Real Time Bus State sub-class code

The next 20 words (words 1 through 20) that will be transferred to DAP 372 also originate from the event queue and will be serialized out in 16 bit words.

10 The order is as follows in Table 24.

Table 24

	Name	Description
	word 1	Detector Commands-field 1 (bits 15:0)
	word 2	Detector Commands-field 1 (bits 31:16)
15	word 3	Detector Commands-field 2 (bits 15:0)
	word 4	Detector Commands-field 2 (bits 31:16)
	word 5	Detector Commands-field 3 (bits 15:0)
	word 6	Detector Commands-field 3 (bits 31:16)
	word 7	Detector Commands-field 4 (bits 15:0)
20	word 8	Detector Commands-field 4 (bits 31:16)
	word 9	Event Queue Information-field 1 (bits 15:0)
	word 10	Event Queue Information-field 1 (bits 31:16)
	word 11	Event Queue Information-field 2 (bits 15:0)
	word 12	Event Queue Information-field 2 (bits 31:16)
25	word 13	Event Queue Information-field 3 (bits 15:0)
	word 14	Event Queue Information-field 3 (bits 31:16)
	word 15	Event Queue Information-field 4 (bits 15:0)
	word 16	Event Queue Information-field 4 (bits 31:16)
	word 17	RT Bus State-field 1 (bits 15:0)

- word 18 RT Bus State -field 1 (bits 31:16)
- word 19 RT Bus State -field 2 (bits 15:0)
- word 20 RT Bus State -field 2 (bits 31:16)

The next 6 words (21 through 26) transferred to DAP 372 are error signals. The next 6 words are transferred in the following order, as set forth in Table 25.

Table 25

Name	Description
word 21	EP Error- (bits 15:0)
word 22	EP Error -(bits 31:16)
word 23	Queue Error - (bits 15:0)
word 24	Queue Error - (bits 31:16)
word 25	Fiber Channel Error - (bits 15:0)
word 26	Fiber Channel Error - (bits 31:16)
System Overview	

As shown in Fig. 1, imaging system 100 provides an upgradeable digital x-ray system, which takes advantage of widely available PC technology for a computer platform. Imaging system 100 runs under a task based, non-real time operating system. At the same time, imaging system 100 provides control of the low level events occurring during image acquisition. High level and low level functions are partitioned for best utilization of resources. In particular, all functions which occur in real-time are pushed down into hardware to remove the burden of real-time operation on the computer operating system. These functions are often better suited to hardware implementation because complex data processing operations are not performed. In contrast, image processing functions such as gain and offset correction are often relatively costly to implement in custom purpose hardware.

Therefore, imaging system 100 uses simple and special purpose hardware for real-time control, and processes image data on host computer 114.

### The Event Sequence

Image acquisition includes a sequence of events, which occur at precisely-timed intervals and involve control of radiation generation system 109 and image detection system 112. In most cases, the user knows an exact order in which these events need to occur well in advance of the image acquisition. This sequence will vary from acquisition to acquisition depending on the type of experiment being performed and the type of information the user is seeking to learn through the image acquisition. Therefore, a list or description of the sequence of event instructions to be performed is constructed. This list is not constructed in real-time and is therefore performed on host computer 114. Once the Event Sequence is known, the details are transmitted to special purpose hardware for execution in real-time.

Returning to FIG. 15, described in greater detail above, a high level description of the image acquisition is generated by acquisition control software, such as test control application 306. This description includes a sequence of frames to be acquired and optionally includes details such as frame time or amplifier gain to be used during acquisition. This Frame Sequence is then translated to an Event Sequence using a compiler which knows the details of the target control hardware. This event sequence is then sent over computer communication bus 302 to detector framing node 304, where it is stored in preparation for execution. Execution of the sequence is initiated by sending a Begin Sequence command over computer communication bus 302. The extent of real-time control allotted to host computer 114 is determining when the sequence will begin. Once the Event Sequence is complete, host computer 114 retrieves the acquired data, in addition to various diagnostics and responses, which were recorded during execution of the event sequence. Therefore, host computer 114 is involved in pre- and post-processing roles and is entirely relieved of the burden of real-time operation.

### The Event Graph

FIG. 49 is an example event graph 650 illustrating a typical sequence for image capture. Example event graph 650 includes a series of isolated events, each

of which is planned to take place at a predetermined point in time. With reference to example event graph 650 and beginning on the left hand side, a series of scrub frames (panel scans with no data returned) are shown. These represent the scrub frames which are taken while detector framing node 304 is sitting idle prior to the event sequence.

5 This idle state is referred to as DFN Normal mode and is the default state of operation. The event sequence is triggered and begins as the system leaves Normal mode and enters Run mode (event sequence execution). The first event instruction in the event sequence, E0, sets up detector framing node 304 for the frame. E1 is the delay time from the start of the first frame until the beginning of readout of the first frame. This is followed immediately by E2, which is an image request, and E3, which is a delay accounting for the image readout time. Once E3 is complete, E4 sets up the next frame and E5 - the delay for the second frame - begins. The frame is readout on E6-E7, and the EndQ event instruction E8 corresponds to the end of the event sequence. When this point is reached, the execution is completed, and the system leaves Run mode to return to Normal mode.

During execution of the sequence shown in FIG. 49, two frames of data are acquired. These frames are transferred directly to computer RAM 334. In addition, commands sent to detector framing node 304 to initiate the readout each result in an acknowledgment being returned from detector framing node 304. This acknowledgment is recorded for each event and stored in computer RAM 334 in the response log buffer 737 (set forth in greater detail below). All of this information along with pointers to the frame data in computer RAM 334 are passed to the top level computer application immediately following completion of the event sequence. The sequence is repeated again by sending another begin sequence command to detector framing node 304 over computer communication bus 302.

#### Standard Event Set

The Standard Event Set for the firmware of detector framing node 304 contains a minimal number of event instructions to support features of imaging system 100. These event instructions are grouped roughly by functionality. Each event

instruction includes a single Op-Code byte specifying the event, followed by the argument bytes to be used when applicable. All op-code words are one byte long and their arguments are multiple bytes long as indicated. Op-code and argument bytes are packed for optimum utilization of the EAB memory 474 on detector framing node 304 in EP 374. Diagrams illustrating the format of control and data words for each event are set forth below. The diagrams show the exact byte order of data in EAB memory 474 beginning with the op-code. Multi-byte words show the byte ordering with "(0)" being the most significant byte.

FIG. 50 is a table of a standard event set 660. All event instructions take one cycle of the 2  $\mu$ sec event clock to be read from EAB memory 474 and processed.

FIG. 51 is a block diagram of Send event 670. This event instruction sends the command words S1 and S2 to a device. The response from detector framing node 304 is recorded in the response log 737 on host computer 114. A Perl Script example to execute Send event 670 follows:

```
Send(0x2001, 1x2);
```

The above example has the format Send("command", "argument") such that different numbers may be used. In this example, a DFN Signature Request command is sent to detector control board 124 in image detection system 112. The reply from detector control board 124 is recorded in the response log 737, and has the exemplary form:

```
ACK1 = 0x20021
```

```
ACK2 = 0x40300100
```

As set forth above, ACK1="command" and ACK2="signature". The detector control board 124 responds with a signature indicating that it is running Cardiac H20 firmware. The send event 670 is used to send a Store Scan Setup Parameters command to detector control board 124. In this case S1 will have the



format of the command, "0x00004020" and S2 will be the 32 bit parameter word to be stored. The send event 670 is also used for the Read Temperature command. In this case, S1 is "0x00004100" and S2 has no effect. After processing this command, detector control board 124 replies with an acknowledge having two 32 bit words, which are recorded in the response log 737. The first of these is a copy of the original S1 word unless the command was not recognized in which case it would be "0x0000FFFF." The second word will be the requested temperature. Send is executed in a single 2  $\mu$ sec tick of the Event Sequence clock. A FC timeout is set with a user programmed register on the card. If this timeout is exceeded without a reply from the device, an error is generated. The timeout for return of Fiber Channel ACKs is set in 28 nsec increments with a timeout of  $1024 \times 28 \text{ nsec} = 28.672 \text{ msec}$ . The timeout is set to a nominal value (e.g. 256 counts) by the DFN driver. Fiber Channel error conditions are detected by detector framing node 304 and passed on to host computer 114 using a PCI interrupt. They are also recorded in response log 737. The send event 670 has a time-out on its execution. The return information is monitored by detector framing node 304 to determine whether the information has been received and processed correctly.

FIG. 52 is a table of reported Fiber Channel errors 672.

FIG. 53 is a block diagram of Delay T event 680. This event instruction provides a delay in execution given by T, where T is a 32 bit binary word representing the number of ticks of the 2  $\mu$ sec event sequence clock. Timing of frame readout is not regulated implicitly by an interrupt system which counts off 30 Hz increments in the background. In DFN Run mode, precise timing of frame readout is maintained entirely by event instruction in the event queue. A Perl Script example follows:

```
Delay(16500);
```

In the Perl script, the argument to this event instruction is provided in ticks of the 2  $\mu$ sec event clock. Therefore the above example measures out a delay of 33 msec which is the frame time for a cardiac image. The Delay event is useful for

generating the delay between successive readouts of detector control board 124. This delay would then constitute part of the entire frame time for the given frame with the remainder of the delay being taken up by the readout operation. This event instruction is also used to account for the delay due to readout of the image data. The Delay T  
 5 event 680 is used to insert a delay between the beginning of a light frame and the point at which radiation generation system 109 is turned on.

FIG. 54 is a block diagram of Loop KN event 684. This event instruction decrements the event queue pointer to allow looping on sections of the event queue. Looping is performed on instructions which occur before the loop event.  
 10 The distance the pointer is moved is given by K, and the number of times the loop is performed is given by N+2. Note that the loop pointer is zero-based and the loop instruction is not reached until the first time through the loop. These two conventions account for the additional two counts which are added to the counter. Note that looping is performed on the event instructions prior to the Loop event, therefore all  
 15 loops are executed at least once (N=0). Currently, N is one byte long and therefore 257 loops (255+2) are allowed. A Perl Script example follows:

```
Send(0x007000, 0x1);
```

```
Delay(16500);
```

```
LoopKN(2, 20);
```

20 In this example, detector framing node 304 is read 22 times at a frame rate of 33 msec per frame. This is accomplished by sending the above image request command, e.g. Send("image request"), followed by a delay of 16500 2  $\mu$ sec counts, and a LoopKN statement. In the Perl file, the jump distance "K" is provided in terms of number of event instructions, whereas in the binary event compiler output COFF  
 25 file, the jump distance "K" is specified in terms of actual bytes. The compiler takes care of performing the mapping between these two ways of specifying the event instruction. The Loop KN event is useful for taking a prescribed number of data frames from detector framing node 304. The loop KN event can encompass a section

of the event sequence which includes both dark and light frames. In this way a long series of images may be captured using a relatively short sequence of event instructions.

FIG. 55 is a block diagram of Loop KF event 686. Loop KF event has a binary format. FIG. 686 shows the order of bytes in EAB memory 474. This order is reversed in the Perl script such that ("TYPE,MASK,STATE" becomes "STATE,MASK,TYPE") due to differences in Endian ordering. This event instruction decrements the event queue pointer to allow looping on sections of the event queue. The distance the pointer is moved is given by K. Looping continues until the F flag is received. F is described by the Type (RT bus = "00", Host Flag = "01"), the Mask and the State. One layer of nested looping is allowed. See Wait F for a description of Flags. A Perl Script example follows:

```

Send("image request");

Delay(16500);

LoopKF(2, 0xA AFF01);

```

In this example, detector framing node 304 is read indefinitely at a frame rate of 33 msec per frame until a Host Flag is received from the user application (see Wait F for Flag definition). This is accomplished by sending the image request command ("image request"), followed by a delay of 16500 2  $\mu$ sec counts, and a LoopKF statement. In the Perl file, the jump distance "K" is provided in terms of number of event instructions, whereas in the binary event compiler output COFF file, the jump distance "K" is specified in terms of actual bytes. The compiler takes care of performing the mapping between these two ways of specifying the event. The Loop KF event 686 is used to synchronize the Event queue to an external input for acquisition of a light frame. A sequence of event instructions incorporating a scrub frame are placed in the Loop KF loop with the event waiting for the flag F from the real time bus 379. Once radiation generation system 109 is ready, the real time bus 379 changes state to F, which causes the Event queue to leave the Loop KF loop and

proceed on to the next event which is a data frame. Together, the X-ray On and data frame realize a light frame, which is in lock step with the previous detector scrub operations. The Loop KF event is used to generate an infinite loop for debugging of detector operation. The loops are made sensitive to a flag from host computer 114 indicating that execution is completed.

FIG. 56 is a block diagram of Wait F event 694, which is a binary format. FIG. 56 shows the order of bytes for the Wait F event 694 in EAB memory 474. This order is reversed in the Perl script ("TYPE,MASK,STATE" becomes "STATE,MASK,TYPE") due to the differences in Endian ordering. The Wait F event 694 pauses execution of the queue until the flag F is received. The exact nature of the flag is determined as indicated above using the TYPE, MASK and STATE fields. Type is used to indicate the origin of the flag (TYPE "00" = RT Bus, TYPE "01" = Host Flag). Mask is used to select which bits are to be tested, and STATE holds the corresponding expected states for the test to pass. For example, in order to turn on bit 0 on the RT bus, the following TYPE, MASK, STATE construction is used: ("00,01,01"). Note that it is possible to turn on any bit independently of any others such that the real time bus 379 does not need to be read in order to change a given bit; the previous state are left unchanged as necessary. The real time bus 379 is read by host computer 114 when using the DFNReadRTBState() function call. A Perl Script example follows:

```
Wait(0x0A0F01);
```

In this example, execution is paused at the Wait statement until the pattern "XA" is received from the computer application. In this case, because the MASK is "0F," the lower nibble of bits of the incoming Host Flag will be tested. In the case of mammography, the operator holds down both a "Prepa" and a "Graphe" button in radiation generation system 109 to initiate an x-ray exposure, with Graphe actually applying voltage to the x-ray tube. A Wait F event in the X queue is optionally made to look for a signal indicating that the Graphe button on the operator console has been pressed. The Graphe button is interfaced using the real time bus 379

and is represented by a single bit which is tested against for state effectively corresponding to a flag. Once this flag is received, executions would move on to the next event instruction, which would be a Flag F command to radiation generation system 109 calling for radiation generation system 109 to be turned on. The Wait F event is used to synchronize the Event queue operation to host computer 114. A Wait F event is used to stop execution until the host computer 114 signals that it is ready to proceed. For example, using a Wait F in an image loop, an operator optionally steps through a series of precisely timed image acquisitions with a keyboard press on host computer 114 used to tell host computer 114 to proceed to the next frame in the sequence. After each keyboard key press, host computer 114 signals the event queue in EAB memory 474 with Flflag F.

FIG. 57 is a block diagram of Flag F event 696, which is in a binary format. FIG. 57 shows the order of bytes in EAB memory 474. This order is reversed in the Perl script ("TYPE,MASK,STATE" becomes "STATE,MASK,TYPE") due to the differences in Endian ordering. This event instruction generates the flag F. The exact nature of the flag is determined as indicated. TYPE is used to indicate whether the flag will be applied to the real time bus 379 (TYPE="00") or will generate an interrupt to host computer 114 (TYPE="01"). MASK is used to select which bits are to be controlled, and STATE holds the corresponding levels for each bit. Flags on the real time bus 379 remain until cleared by a subsequent event. Flags sent to host computer 114 cause a single interrupt to be generated and cause the flag value (STATE x MASK) to be transmitted to the computer application. A Perl Script example follows:

```
Flag(0xB1F100);
```

In this example, a real time bus flag (TYPE="00") is generated. Since the MASK is "F1" the upper four bits are all changed to the state specified "B", while of the lower four bits, the least significant bit is changed. The Flag F event is used to generate the X-Ray on signal for turning on radiation generation system 109. This is done by selecting the appropriate bit on the real time bus 379 and then setting it to the

desired level. This bit can later be cleared using another Flag F event. The Flag F event is used for computer-synchronized image acquisition to generate a flag to host computer 114 indicating that the Graphe button has been detected by a previous Wait F event. Host computer 114 optionally uses this information to signal image acquisition status.

FIG. 58 is a block diagram of End Q event 697. This event constitutes the end of the event sequence. When this event is reached, detector framing node 304 passes from Run mode to Normal mode, and notifies host computer 114 that execution is complete. ENDQ event 697 is inserted automatically by the event compiler and is not present in the Perl script.

Examples of typical event sequences, which may be implemented, are set forth below. They are intended to demonstrate the flexibility of the architecture proposed herein. Each example includes an event graph illustrating the sequence execution in time. The graph is accompanied by a representation of the Event queue for the sequence.

FIG. 59 is an event graph 698 for a mammography sequence. Image acquisition for mammography provides a good example of an event sequence controlled by external events. Present is an example of a typical mammography digital x-ray acquisition based on radiation generation system 109. The tester system has access to the Graphe push button as a signal on the real-time bus 379 indicating that voltage is applied to the x-ray tube. X-ray On time in this simple example is set manually by the user as part of the technique set at the console (i.e. mAs). The tester has control over the beginning of the x-ray exposure through the real-time bus but does not control the on-time directly. It is up to the application code to set up the Event queue correctly to allow for the expected delay due to the given mAs setting.

FIG. 60 is a block diagram of event queue 700. The start of the sequence is initiated by host computer 114 using the Begin Sequence command on computer communication bus 302 once the queues have been properly setup. At this point the detector framing node 304 leaves Normal mode, and begins sequence

execution. The Event queue begins by looping on scrub frames and waits for the Graphe button to be pressed (RT1). As illustrated in the graphs, this is accomplished using events E0-E2, where E1 is a Send event for a Scrub, and E2 is a LoopKF event. The control event E2 takes as defining arguments the flag RT1 which will end the loop as well as the distance K to jump back to the event which begins the loop. In this case K=2 since the loop contains two events. RT1 is a flag from real time bus 379 defined by specifying which signal to monitor (for the Graphe press) and the state to look for (high or low). Once Graphe is pressed, the Event queue detects this change and leaves the scrub loop because image acquisition will begin.

The next group of events in the sequence initiate the offset or dark frame acquisition and then provide the synchronization between the start of the light frame and the start of the x-ray exposure. These events correspond to E3-E10. E4 is a Send event which sends an Image Request to detector framing node 304. Note that the readout delay for the image request is accounted for using the Delay event E5. Once E5 completes execution, data has been stored locally on the DFN in a frame buffer. The completed acquisition triggers direct memory access of this frame buffer to host computer 114 over computer communication bus 302. X-ray exposure is phased relative to the start of the light frame; E6 provides this time delay. Following the delay, E7 sends the X-ray On signal by changing the value of the flag RT2 corresponding to the X-ray On signal on the real time bus 379 to radiation generation system 109. As mentioned previously, the current mammography test system does not have the facility for setting the duration of the X-ray On time. Therefore, this X-ray On signal tells the radiation generation system 109 when to begin exposure, and X-ray Off is not used. The sequence ends when E11 terminates the queue. The EndQ event moves DFN from Run mode back to Normal mode to idle and scrub the panel.

FIG. 61 is an event graph of a Gated Cardiac Sequence 702. Image acquisition of a gated cardiac sequence provides a slightly different example of an externally controlled event sequence. It is assumed that a trigger signal on the real-time bus provides the gate to control when images are acquired during a frame

sequence. Such a gating signal might be provided by a heart monitor to synchronize light image acquisition with certain phases of heart activity.

FIG. 62 is a block diagram of event queue 704. As in the mammography digital x-ray case, the start of the sequence is initiated by host computer 114 using the Begin Sequence command on computer communication bus 302.

At the start of the sequence, the WaitF event E0 pauses sequence execution until a heart beat is detected on real time bus inputs (RT1). When the beat arrives, detector framing node 304 is scrubbed once (E1-E2) to begin the panel integration time. The x-ray is then turned on at E3. Assuming that the generator turns off automatically after 10 ms, E4 waits for this period to complete. E5-E6 complete the integration period and readout detector framing node 304. The entire construct of E0-E6 is looped using E7 which waits for Host Flag HF1 from the computer application telling the sequence to exit with the EndQ, E8.

The sequence runs continuously and synchronizes with the heart beat until computer application tells it to exit. Alternately with two layers of nested looping it would be possible to scrub the panel at a set rate until the heart beat was detected. One loop would scrub the panel, and the second loop would repeat the entire construct (scrubbing + single image acquire) until the computer application signaled done.

#### DFN Autoscrub Feature

FIG. 63 is an event graph of autoscrub sequence 706. In addition to image requests sent during Event Sequence execution, detector framing node 304 is able to send Scrub requests automatically at a user programmed rate while in DFN Normal mode. To use the Autoscrub feature, the user application first sets up the desired rate to scrub at. This is done using, e.g. a DLL function call DFNSetAutoscrubDelay() (defined generally below), which takes as its argument the



scrub frame time in 2  $\mu$ sec counts. The user application also turns on an autoscrub feature when it is intended to be used with a function call.

### Detector Equilibrium

The image detection system 112 is scanned at a constant rate while  
5 images are not being acquired in order to prevent degradation in image quality or  
damage to flat panel detector 116. Detector controlled firmware, i.e. firmware  
controlled by detector control board 124, is designed to enter an autoscrub mode when  
sitting idle for a long period of time. In typical operation however, flat panel detector  
116 is scrubbed continuously when images are not being acquired. For this reason,  
10 detector framing node 304 is designed to scrub flat panel detector 116 while in  
Normal mode if the user turns on this feature.

### Timing Transitions

In order to prevent image artifacts from occurring, a seamless transition  
is provided from a detector framing node idle state to image acquisition. A detector  
15 framing node autoscrub feature scrubs detector framing node 304 at the user set rate  
until a BeginSequence request is received. To maintain strict timing, the Event Queue  
waits until the frame time for the last scrub completes before beginning execution of  
the event sequence. Therefore, a perfect transition occurs if the first event in the queue  
is either a detector scrub or an image request. On termination of the event sequence,  
20 the event queue immediately begins autoscrub by sending a detector scrub command  
when the EndQ is encountered. Therefore, a perfect transition on termination occurs,  
if the last two events in the queue (excepting the EndQ) are a scrub (or image request)  
followed by a delay time which is identical to the programmed delay in the DFN  
autoscrub frame time register.

### Configuration and Use

#### Bus Driver Configuration

Real time bus 379 is bi-directional. Control of the direction of each channel on the bus is accessible to the user using the DFNSetRTBDirection() DLL function call (set forth in greater detail below). On power-up, all real time bus channels start out as inputs. Even though the Event Sequence may drive a channel high, in reality, the channel will continue to be in a high-impedance state until its driver is turned on by the user application. Therefore, the direction of all real time bus channels are set prior to the beginning of the event sequence.

#### Setting the Default State

Detector framing node 304 maintains a default state for the real time bus drivers. This feature is designed to return the bus to a "safe" condition in the event that a system error occurs. The default state is also set using the DFNSetRTBDirection() DLL function call (set forth below). The user application sets the value of the default state prior to the beginning of the event sequence.

#### Queue Variables - Real-Time Sequence Control

Queue Variables provide communication between the computer application and the Event Sequence. They are used to change parameters on the fly and can also be used to setup a generic frame template before beginning an image sequence. This second application removes the requirement for repeated compilation of Perl scripts when changing parameters such as frame time or Common Electrode Voltage between acquisitions.

Queue variables act as ASCII "keys" identifying numbers in the Perl script which are changed by the user application. The user application uses DLL function calls to pass values for the given keys down to detector framing node 304. These values are written to an area in EAB memory 474 which is separate from the event instructions themselves and is referred to as "Queue Variable Space". When the Event Queue reaches an instruction in the queue which has a Queue Variable in its argument, the queue reads an address which points it to the current value of the Queue Variable in Queue Variable space. The Queue then processes the instruction using the

current value of the Queue Variable. The user program can change this value at any time before or during Queue execution since detector framing node 304 prevents the Queue from reading Queue Variable values while they are being written. When a Queue Variable is changed by host computer 114, the value of the Queue Variable is updated immediately in EAB memory 474, however the effect of this updated value appears when the particular event instruction, which uses the particular Queue Variable, is reached by the Event Queue.

#### Queue Variables - Real-Time Sequence Control

Queue variables provide communication between a host application and an event sequence. Queue variables are optionally used to change parameters on the fly, such as during image acquisition, and are optionally used to setup a generic frame template before beginning an image sequence. The use of a generic template removes the requirement for repeated compilation of Perl scripts when changing parameters such as frame time or Common Electrode Voltage between acquisitions.

Queue variables act as ASCII "keys" identifying numbers in the Perl script which can be changed by the user application. The user application uses DLL function calls to pass updated values for given keys down to DFN 304. These values are written to an area in EAB memory 474, which is separate from the Event instructions, and is referred to as "Queue Variable Space." When the Event Queue reaches an instruction in the queue having a Queue Variable in its argument, the queue reads an address, which points to the current value of the Queue Variable in Queue Variable space. The Queue then processes the instruction using the current value of the Queue Variable. The user program optionally changes this value at any time before or during Queue execution. Conflicts are avoided since DFN 304 prevents the Queue from reading Queue Variable values while they are being written. When a Queue Variable is changed by the host, the variable value in EAB memory 474 is updated immediately, however the effect of this updated value appears when the event instruction, which uses the particular Queue Variable, is reached by the Event Queue.

## Perl Script Queue Variables Scope, Definition and Use

All arguments to event instructions defined in a Standard Event set (with exception of loop jump distance K) are optionally parameterized using Queue Variables. For example, a Queue variable is optionally defined for the N value of a LoopKN event. Thus, the user application may optionally change the number of repetitions in a frame sequence without recompiling the respective COFF file. By defining a Queue Variable for the Send event, the user optionally parameterizes all detector parameters, since these are set using detector commands initiated by the Send event. Similarly, frame time can be parameterized by defining a Queue variable for the Delay event in a frame.

### Defining and using Queue Variables

In the Perl script, Queue variables are defined in the preamble to frames as well as at the top level of the hierarchy. They are given a default value, which is the value that will be loaded into their memory location when the COFF file is written to EAB memory 474. The default value can be defined either at the frame level or at the hierarchy level for additional flexibility.

FIG. 64 illustrates a top level Queue variable definition format. FIG. 65 illustrates a frame level Queue variable definition format. In this example, the Queue Variable delay\_qv is defined to parameterize a Delay event instruction. Queue Variables are not typed, however they need to be assigned defaults. An assigned default is performed for delay\_qv at the frame level, where it is set to a default of 20 msec. An assigned default is also performed at a top level, where it is set to 10 msec. As with Queue Parameters, top level definitions take precedence with the frame level default being used in the event that a top level default is not assigned. As with the Queue Parameters, the function call for the frame as well as the compile\_init call are passed for the list of Queue Variables (%qv) to be activated. Once the defaults have been the defined, the Queue Variable is used by simply replacing the number in the

event instruction argument with the name of the variable. Single quotes are used for the variable to be recognized.

### Using Queue Variables in User Application

In order for the user application to update the values of Queue Variables on DFN 304, the user application needs a reference to the Queue Variable location in EAB memory 474. This reference is provided in the form of an ASCII key, which is the same as the name of the Queue Variable as it is defined in the Perl script. A table mapping the ASCII keys to their respective memory locations in DFN memory is stored in the COFF file upon compilation. This table is called the Queue Variable Symbol Table, and is passed to the DLL when the COFF file is read. The DLL uses this table to look up memory locations when provided with ASCII keys for Queue Variables.

### Changing a Queue Variable using DFNChangeQueueVariable()

FIG. 66 is a format of a function call having defined ASCII names. The user application updates values of Queue Variables in DFN memory using the DFNChangeQueueVariable() DLL function call. As illustrated in FIG. 66, the format of this function call provides that SymName is the ASCII name of the Queue Variable, which is identical to the name defined in the Perl script, and sndBuf is the value of the Queue Variable, which will be written into DFN memory. BuffSize is the number of bytes which will be written, and debug provides the DLL developer with feedback on success of the call.

Queue Variables correspond to the arguments of event instructions, and since these have different sizes depending on the type of event, the user specifies the number of bytes to be written using Buffsize.

### Integrated Queue Variables Example

When using Queue Variables, the source code of both the user application and the Event Sequence are planned together so that the system functions as an integrated whole.

FIG. 67 is an example application explaining source code for a C++ user application. The illustrated Queue Variables example involves an event queue looping indefinitely on an image capture, the frame time of which is determined by a variable that is modified by the host application in real-time. The source code for sections of the user application and the event sequence together implement the above behavior.

FIG. 68 is an example application explaining a Perl script event sequence. In the Perl script, the image acquisition includes an image request, `Send($image_cmd)`, followed by a delay, which incorporates both the integration time and the readout time: `Delay(delay_qv)`. This delay is parameterized using the queue variable `delay_qv`. Note that `delay_qv` is initialized to 20000 counts of the 2  $\mu$ sec event clock amounting to 40 msec of delay2. Also, there is a distinction between Queue Variables, which use single quotes, and Perl variables, which use a "\$" prefix. The `LoopKF` statement is used to loop on image acquisition until a host flag (0xAFF01) is received from the user application telling the queue to stop. During this period, the user application optionally changes the frame time at any point by updating `delay_qv`.

Since the user application and the event sequence run asynchronously with respect to each other, the exact moment that the queue variable is changed is unknown. The exact moment when the value is used, however, is precisely defined because this is the point when the `Delay` instruction is next evaluated. If the queue variable change is to be synchronized with the event queue execution, this can be accomplished using host flags. The event queue optionally notifies the user application a short time in advance of the point where the variable needs to be updated so that the host will have enough time to make the change.

On the host application side, the host begins by starting a HF.bin coff file running. This file contains the compiled code for frame\_type1. In the simplified example of FIG. 69, the host application then proceeds to update the queue variable with a value for the delay. Alternatively, the user application waits for a host flag to tell that the sequence has begun running. The user application then polls the keyboard or takes input from a GUI telling it whether the particular variable should be incremented or decremented based on an operator request at the time.

Alternately, the user application takes input from the user prior to running the sequence and updates the queue variable right before issuing the BeginSequence. This is useful, for example, when running a series of tests in which the format of the acquisition is the same but the frame time changed each time the test is run. Using queue variables in this case allows the user application to make changes to the frame time without having to recompile the COFF file.

For complex testing using a C++ program to generate sophisticated variations in acquisition parameters, the user application optionally runs repeatedly synchronized with the event queue. Each time through the loop on the user application side various acquisition parameters are updated. For example, the frame time is optionally varied from 20 msec to 100 msec in 100  $\mu$ sec increments, while after each set of frames, the average pixel level is calculated and used to set the Common Electrode voltage for the next image or image group. On the Event Queue side, after each image or group of images, the queue then notifies the host that it was done and waits until the host is ready for the next image acquisition before continuing. When the acquisition is completed, the host then aborts the sequence to exit the loop.

#### Image Acquisition

A performance goal of image acquisition is to acquire and display images in real-time. For 1k x 1k cardiac/surgical digital x-ray images, acquisition and display rate is 30 frames per second. However, for recorded images, a different rate is optionally used. A display rate of 30 frames per second displays a flicker with a 60 MHz PC. Typically, a review work station will run at 70 MHz. This avoids vertical

blanking of the display. For 2k x 2k fluoro-radiography digital x-ray images, the acquisition and display rate is 7.5 frames per second. The acquisition and display rate for other image sizes (regions of interest) or other panels may be different.

The choice of operating system influences design of system architecture. The more involved the operating system is in the acquisition of an image the more likely the operating system is to drop an image. Failing to display a small number of frames in a 30 frame per second sequence could go unnoticed. A similar failure at the 7.5 frame per second fluoro-radiography rate would be more noticeable (particularly with a moving phantom), but would be acceptable.

The acquisition process minimizes the involvement of host computer 114. The available memory is partitioned into a section managed by the operating system and a second section is managed independently of the operating system. Logistically, an option is applied to the boot configuration (boot.ini) that limits the operating system to the lower 256 MBytes (TBD) of physical memory.

The driver for DFN 304 manages the physical memory above this boundary. At the start of an acquisition, the driver divides the available physical memory into 2 MByte blocks. However, for radiography digital x-ray, multiple 2 MByte blocks are used to make a single image. A list of physical addresses is passed by the DFN driver to the acquisition card. As each image arrives, DFN 304 copies the image to the next physical address on this list and interrupts host computer 114. At some time host computer 114 services this interrupt. An unlikely scenario would be for DFN 304 to copy an image and interrupt host computer 114 more than once before host computer 114 serviced the interrupt. Host computer 114 can detect this situation because DFN 304 has a register that allows host computer 114 to determine how many images have been transferred.

The device driver for DFN 304 maintains a list of available image buffers. Each time the computer application is ready to process an image, the driver passes an image address to the computer application. The WINDOWS NT ® operating system provides services that allow the driver to map these image buffers



outside of the region managed by the operating system. The driver has an option that will let it reuse these buffers after host computer 114 has displayed their contents. If the computer application determines that it is not keeping up with the input image stream, it can programmatically skip the display of one or more image buffers.

5                   FIG. 70 is a block diagram of a memory map architecture shared between DFN 304 and computer RAM 334 of host computer 114. As illustrated, the physical computer memory 362 in host computer 114 includes mapped virtual memory, AGP memory, and unmapped virtual memory. The mapped virtual memory is displayed on high resolution display 338. More than one 2 MByte buffer may be used to store a single image. One image is displayed at a time with a cache of mapped frames.

10                   In continuous display mode, an application has allocated some number, "N," image buffers in DFN memory unit 380. At any given time the last "N" images are saved in these buffers. If the computer application programmatically skips one or more of these last "N" images, the image data is still available. The other possible operating mode is that the computer application acquire "N" images. In either scenario none of the "N" images that the computer application wanted to keep has been lost, even if the application did not display the image. These buffers are not mapped. There are unavoidable latencies in any data acquisition system. DFN 304 has 10 MBytes of buffer memory to help absorb latency. Buffering, together with careful system design minimizes the possibility of dropped frames.

15                   There are a number of advantages to this image acquisition strategy: host computer 114 is not directly tied to acquisition of individual frames. The image buffers are physically contiguous such that DFN 304 does not manage multiple memory extents. An extent is a physically contiguous block of memory. A 2 MByte cardiac image therefore has 512 memory pages, with a page being 4096 Bytes on PENTIUM ® class processors. There can be as many as 512 extents in this image if no two memory pages are physically contiguous.

The computer application does not address the operation of paging individual memory pages by the operating system from an image. This paging activity affects the time used to process individual images. Image files can be quite large. According to an operative embodiment wherein the operating system is WINDOWS NT ®, a 2 GByte virtual address space is provided. According to an alternative  
 5 embodiment, WINDOWS NT SERVER, ENTERPRISE EDITION ®, has a 3 GByte virtual address space. During operation, a few images are included in virtual address space at any given time.

According to an operative embodiment, a WINDOWS NT ® driver  
 10 directly manages DMA. In this case, a computer application passes the virtual address of a buffer to the driver. The driver locks the individual pages of this buffer in memory and builds a list of physical addresses. The resulting list is similar to a scatter-gather list. The operating system provides routines to perform DMA using the list of physical addresses that the driver has created. In this case, host computer 114  
 15 initiates DMA rather than initiation by DFN 304. This approach is also not preferred because the computer application contends with paging of the image buffers and all the image buffers are subject to the limitation on available virtual address space. Host computer 114 is involved in each DMA. Buffering on DFN 304 permits latency caused by host computer 114. If host processor 115 is too busy to respond to a DMA  
 20 done interrupt, it is not going to be able to perform the image processing and display. This technique is optionally used to manage image acquisition.

The action of detector framing node 304 for image transfer removes host processor 115 from image acquisitions. With detector framing node 304, hard-  
 25 real time requirements are satisfied, such as capturing every image in a sequence, without requiring use of a real-time operating system. Detector framing node 304 does not perform scatter-gather DMA because the physical address of each buffer is aligned on a host memory page boundary and because each buffer is physically contiguous.

Conventional systems request one or more images from an image acquisition system. Typically, each request is for a single image, but an application may have multiple requests outstanding. Limitations of the host operating system normally prevent an application from queuing requests for an entire sequence. Modern high performance devices, like those used for image acquisition, traditionally use DMA to transfer data to or from host memory. DMA is a relatively complicated procedure to set up. Host processor 115 becomes involved at several different times to complete the transfer request. The traditional host operating system processes each transfer request individually. If the operating system supports virtual memory, the operating system makes sure that none of the memory pages in the target address range get swapped to disk while the transfer is pending. Different operating systems describe this operation in distinct fashions. Under embodiments of WINDOWS NT ® and WINDOWS 2000 ®, pages are optionally locked. There is also an additional probe operation to guarantee that the target pages are accessible. Other operating systems perform similar tests. Neglecting this detail creates security problems and the use of a probe and lock operation is relatively expensive.

A device driver that functions as an extension of an operating system is responsible for communicating with the image acquisition hardware. The operating system normally probes and locks pages before passing the request to the driver. Alternatively, the driver performs the above bookkeeping when the driver receives a transfer request. The embodiment of WINDOWS NT ® supports both techniques. The device driver then allocates resources needed to set up DMA.

Applications typically work with virtual memory addresses. These addresses require access to a memory management unit ("MMU") of a host processor. The use of the MMU is not available during DMA. However, the device that controls the transfers works with physical addresses. Even though the target addresses are virtually contiguous, they are not physically contiguous. In fact the physical addresses may be very fragmented. Each range of these fragmented physical addresses is called a "memory extent" or simply "extent." The driver passes a list of extents to the acquisition device. The list of extents frequently consumes a number of very limited

resources. Thus, the driver may not be able to describe the entire image transfer in a single request. Furthermore, the DMA hardware interrupts the host processor each time a transfer having one or more extents has completed.

5 In the best case scenario using conventional memory management techniques, the host processor is involved in initiating the transfer and in completing the transfer. It is common that the code that completes the transfer actually initiates the next request. The host processor is involved once per transfer. In the worst case scenario, the transfer is split into a number of requests due to resource limitations. Non-real time operating systems cannot bound the interrupt latency (the time used to  
10 respond to an interrupt). If the host processor running a non-real time operating system responds too slowly to an interrupt, it will lose image data.

Detector framing node 304 completely removes host processor 115 from the acquisition scenario. Prior to beginning image acquisition, the device driver on host processor 115 passes a list of physical addresses to detector framing node 304.  
15 These addresses are outside of the memory that the host operating system manages. Each address in this list describes a reasonably large physically contiguous block of memory (e.g. enough to hold an entire image). The detector framing node 304 treats this address list as a circular queue. When an image becomes available, detector framing node 304 removes an address and initiates DMA to host computer 114. When  
20 the transfer completes, the detector framing node 304 sends an interrupt to host processor 115. Host processor 115 does not have to respond to this interrupt in a fixed time window.

When the next image is available, the detector framing node removes the next address from the address list and initiates another DMA, even if host  
25 processor 115 has not responded to the first interrupt. Because the interrupt request remains asserted until host processor 115 services the interrupt, the second transfer will not cause a second interrupt. Detector framing node 304 maintains state information such that the device driver on host processor 115 determines how many images have been transferred. The list of physical memory addresses that the device

driver passes to detector framing node 304 has N entries. The device driver requests that the detector framing node 304 stop after acquiring N images, or the device driver optionally requests the detector framing node 304 to acquire images continuously. In the latter case, the last N images are saved on the host computer 114 (assuming that N or more images are acquired).

Application software running on host processor 115 optionally requests successive images. The application can display, archive, or otherwise process the images. If host processor 115 is not keeping up with the incoming image sequence, host processor 115 can ignore one or more images. Whether host processor 115 processes each image or not, images will not be lost outside of a requested save window (i.e., capture and save N images, capture images continuously and save the last N images).

#### Image Processing

A task based operating system running in imaging system 100 meets processing requirements to perform offset, gain, and bad pixel correction as well as supporting window-level operations for contrast management. To complete the image processing within the available time, a Pentium class MMX instruction set is utilized. These instructions permit host processor 115 to operate on four 16-bit values simultaneously. More than four operations may actually be performed at a time because host processor 115 is super-scalar. Host processor 115 is capable of issuing two MMX instructions in a single clock. Performance is sustained when host processor 115 and computer RAM 334 are integrated such that host processor 115 can actually can issue two instructions per clock.

Memory is accessed systematically so that most data comes from the cache and host processor 115 does not wait for a relatively slow memory read to complete. By processing each image in its natural order (i.e. in the order pixels are stored in memory) and observing the recommended 32-byte alignment of all data structures, performance is improved.

Each PENTIUM ® class processor has on chip (L1) data cache and on chip instruction cache. In addition to the on chip cache, each PENTIUM ® class processor has a secondary (L2) cache. Data and instructions flow from memory to L2 cache to L1 cache. Performance is optimized by operating out of L1 cache and the lesser performance is found operating out of memory.

Processing algorithms are very compact; managing the instruction cache is not significantly involved. The L1 data cache is 4-way, set associative. The unified L2-cache is 4 way, set associative. The lowest five bits of a virtual address specify an offset into a cache line. The next 7 bits of the address specify the cache line. The processor manages the cache ways with a pseudo least-recently-used (algorithm). Each time host processor 115 fetches a different cache line from memory, host processor 115 displaces the "oldest" of the four candidate lines. Fixed binary arithmetic is used having ten bit integer and 15 bit fraction.

FIG. 70 is a schematic diagram of a constant memory format organizing constant data (offset, gain integer, gain fraction). The input image has a page alignment. This data organization has another beneficial side effect on the generated code. The compiler tries to keep frequently used addresses in a limited number of index registers. If separate arrays for the input data arrays are used, as well another register to hold the address of the corrected image, the compiler runs out of index registers. If these three arrays are allocated contiguously but not interspersed as in the previous list, the compiler can use one register to point to the base address, but it requires large offsets to get to the individual components (gain integer, gain fraction, offset). These large offsets affect the capability to decode > 1 nsec/clock. A lack of instructions eventually starves host processor 115.

The high data rates and large volume of data associated with digital imaging makes it difficult to monitor a digital x-ray detector in image detection system 112 in real-time. However, imaging system 100 provides a number of monitoring and trace points. These features are useful, as well as flexible and configurable. Capturing a large volume of system diagnostic information degrades

system throughput to the point where it is not suitable for its intended application. Failure to provide access to certain data, however, can make diagnosing problems difficult. Further, one cannot predict features and capabilities of different detectors or ways in which one can use existing technology. The problem becomes more difficult if one performs image acquisition on a non real-time computer. As set forth below, monitoring of arbitrary detector functions are provided in a completely configurable manner on a non real-time acquisition computer.

One or more events control x-ray image acquisition. X-ray image acquisition events may produce zero or more digital radiosopic images. Some of events control image detection system 112, while others control radiation generation system 109 and synchronize with the external environment. The events are pre-computed and the results are downloaded as resulting byte-code into detector framing node 304. The detector framing node 304 controls both radiation generation system 109 and image detection system 112. The detector framing node 304 executes detector and x-ray events on a 2  $\mu$ sec clock. Each detector command contains a bit flag designating whether detector framing node 304 traces the command. Additionally there is a frame parameter register to control generation of this information. Any spontaneous detector acts generate a response log entry.

During image read-out, response log entries include start of image (SOFN1), start of packet (SOFN2), and end of image (SOFN3). Any event queue optionally sends its start time, event name, and argument to response log 737. A loop command also optionally generates a response log entry for each iteration. DMA completion provides a response log entry that includes a time stamp, an ordinal image number for both the sequence and buffer position, DMA packet size, and the computer memory address of the transfer.

The ability to trace the acquisition at each detector command provides flexibility as set forth below. An engineer enables tracing on a command by command basis and as appropriate for the problem attempting to be solved. In normal operation, tracing is minimized or eliminated to avoid hurting system performance. Each trace is

called a response log entry. A response log entry is 32 Bytes in length and includes a time stamp, the two command words sent to the detector framing node 304, two command acknowledgments received from the detector framing node 304, an image tag, and acquisition started event.

5                   The resolution of the time stamp is equal to the rate at which DFN 304 interprets byte code. Host computer 114 provides DFN 304 with the physical addresses for two separate PC buffers in computer RAM 334. Each PC buffer is page aligned, physically contiguous, and an integer multiple of 32 Bytes in length. By making each PC buffer contiguous, computer memory management details are hidden  
10                   from DFN 304 and bookkeeping procedures that DFN 304 performs are greatly simplified. DFN 304 accesses a selected PC buffer with a simple direct master DMA cycle.

                  When the one of the two PC buffers is full, DFN 304 switches to the other buffer and interrupts host processor 115. The host processor 115 empties the  
15                   first selected PC buffer before the second buffer PC fills. The host processor 115 can configure the size of this selected PC buffer. In normal operation, host processor 115 will make the selected buffer large enough so that there is very little overhead in servicing response-log buffer-full interrupts. Since the 16 MByte/sec rate at which the DFN 304 can fill response log buffers is significantly less than the rate at which the  
20                   host computer 114 can copy data from this selected PC buffer, it is very unlikely that host processor 115 cannot keep up. In the event that DFN 304 fills up the second PC buffer before host processor 115 empties the first PC buffer, DFN 304 stops writing response log entries and generates an error.

                  Under some circumstances, a computer application might not want to  
25                   wait for a large response log buffer to fill. In this case, DFN 304 is able to switch response log buffers on command. Registers on DFN 304 indicate the amount of data in each PC buffer and indicate the currently active PC buffer. There is a potential race condition that occurs if the computer application requests a buffer switch as DFN 304



initiates filling a PC buffer. This problem is avoided by ignoring requests to switch when the current response log buffer is empty.

FIG. 71 is a block diagram of operating system and driver interface 730. The DFN device driver 314 is described for design and function a WINDOWS ® platform operating system. In particular, and according to an operative embodiment, DFN device driver 314 is designed to run on the operating system of WINDOWS NT 4.0 ®, SP5. The operating system does not let user programs directly access hardware. Device driver 334 is a kernel-mode program that provides an interface to access hardware and also controls DFN hardware interactions with the operating system.

As illustrated, interface 730 includes a plurality of user interfaces 732, which interfaces with operating system kernel 734. Operating system kernel 734 interfaces with device driver 334, which in turn interfaces with detector framing node 304. When DFN 304 receives an image from image detection system 112, it transfers the data to computer RAM 334 by DMA. Normally, operating system kernel 734 controls all memory on host computer 114. Memory may be fragmented or organized in a way such that performance of DMA operations by DFN 304 become exceedingly complex. DFN 304 uses DMA to input an image into a contiguous memory buffer in computer RAM 334.

To maintain large, contiguous memory buffers that DFN 304 can use for images, the upper part of computer RAM 334 is "taken away" from operating system kernel 734 by a boot-time parameter called MAXMEM. Memory below MAXMEM is managed by operating system kernel 734 and memory above MAXMEM is managed by the DFN device driver 334. For example, in a system with 512 MByte of RAM, MAXMEM may be set to 128 MByte. Addresses from 0 - 128 MByte are controlled by operating system kernel 734 and hold the operating system, device drivers (including DFN device driver 334), and user programs. Addresses from 128 - 512 MByte, which operating system kernel 734 does not manage, are used by the DFN device driver 334 and the DFN hardware. Registry values help DFN device driver 334 configure this space.

### Organization of memory above MAXMEM

The DFN device driver 334 and DFN 304 use the space above MAXMEM for three things: 1) response log buffers, 2) a list of physical addresses DFN 304 will transfer images to during acquisition, and 3) detector images. By its design, DFN 304 is able to map a section of computer RAM 334 into its address space. This "shared DFN window" is limited to 2 MByte. DFN 304 writes response log entries to this space. DFN 304 also reads a list of physical memory addresses from this space which detector images are transferred to. The list of physical addresses points to buffers which lie above MAXMEM and which are also outside of the 2 MByte shared DFN window.

FIG. 72 is a block diagram showing the memory configuration of computer RAM 334. This arrangement is used by the DFN device driver 334. As illustrated, operating system kernel 734 lies between 0 and 128 MByte. The physical address list 736, response log buffer A, and response log buffer B lie between 128 and 130 MByte, and detector images are located between 130 and 512 MByte. The list of physical addresses can have no more than 65,536 (64K) 4-byte addresses in it (for a total of 256 KB) and the buffer holding this list is on a 256 KB physical address boundary. The response log buffers start on a 4 KByte physical address boundary and are an integral number of response log entries in size (32 Bytes/response log entry). Each response log buffer is not larger than 262,144 Bytes or 8192 response log entries.

### Physical Addresses List

During acquisition, detector images, also called "frames," are read. Each image goes into a buffer in the "Detector Images" memory range of FIG. 72. The collection of images is called a "sequence" and has a unique identifier. More than one sequence can be in memory at a time, although one can be "current" at a time.

Before acquisition begins, the user tells DFN device driver 334 to allocate a sequence of some number of frames. DFN device driver 334 creates a list of

addresses, one per frame, in the detector Images area. This list is given to DFN 304 in the Physical Address List area 736 of the shared DFN window.

FIG. 73 is a block diagram showing how computer RAM 334 looks for two allocated sequences, i.e. one of which is current and available to take data. As images arrive on DFN 304 from image detection system 112, the firmware walks this list of addresses and performs DMA of the image from DFN 304 to computer RAM 334. The user can request a pointer (called a "map request") to these buffers which it uses to access the image for display, calculations, archive, etc.

Converting the physical address to a virtual address suitable for use by a user program, i.e., mapping, consumes WINDOWS NT ® resources called page table entries ("PTEs"). This is a limited resource, which means that a program can use a certain amount before an error occurs. If an unlimited number of simultaneous maps were allowed, DFN device driver 334 would use all system PTEs and WINDOWS NT ® would crash. To address this, 30 MByte of data is allowed to be mapped at once. This is independent of detector size. So, for cardiac/surgical digital x-ray, having a 2 MByte image size, 15 images can be mapped at once. For radiography digital x-ray, having an 8 MByte image size, 3 images can be mapped at once. The registry key that controls PTE consumption is PhysicalMemory/MaximumPageTableEntries. One page table entry is used for each page of memory mapped. A page of memory in WINDOWS NT ® is 4 KByte. Therefore, for 30 MByte of memory,  $30 \text{ MByte} / 4 \text{ KByte} = 7680 = 0x1E00$  PTEs are needed.

The registry setting can be changed to allow for more data to be mapped. However, setting this number too high may crash the system. If the system crashes, the blue screen will show an error condition of "NO MORE PTEs" and this value is manually lowered by changing the registry key. This section deals with the number of images that can be mapped simultaneously. If a user program tries to map too many images at once, DFN device driver 334 returns an error. The user program then unmaps one or more of its mapped buffers before reissuing a map request.

During real-time acquisition, buffers are unmapped in the order they were mapped. This is not true for archive (non-real-time) playback.

If Wrap is disabled for the acquisition, the firmware can transfer up to a set number of buffers. If more images arrive from image detection system 112, an  
 5 overwrite error is generated by DFN 304. If Wrap is enabled for the acquisition, the list of addresses is treated as a circular queue. When a buffer is mapped and then unmapped, DFN device driver 334 updates a tail pointer to let the firmware know that the user has used the data buffer. The firmware will not overwrite an unused data  
 10 buffer. If the user code can not map and unmap buffers fast enough, images will arrive faster than they can be consumed, and the firmware will generate an overwrite error. In wrap mode, at most the last "n" buffers will be in memory when acquisition ends, where "n" is the number of frames in the sequence.

#### Response Log Buffers

DFN 304 optionally generates response log ("RL") entries that user  
 15 programs can use to detect events in image detection system 112 along with associated timing. The RL entries are stored with image data to give a record of the test and to help interpret image detection system 112 data. At startup, the DFN device driver 304 gives the DFN firmware two buffer addresses and a buffer size which will hold RL entries. These buffers lie in the shared DFN window, are each the same size,  
 20 and are an integral number of RL entries big. An RL entry is 32 Bytes.

During operation, RL entries are written by the firmware into RL  
 buffer A 738. When the buffer fills up, an interrupt is sent to DFN device driver 334 and the firmware writes further entries to RL buffer B 740. DFN device driver 334 will dispose of the data in buffer A 738 (based on directions from the user mode  
 25 program described below) and mark it as empty. When the firmware fills RL buffer B 740, a buffer full interrupt is sent to DFN device driver 334 and the firmware flips back to filling RL buffer A. Again, DFN device driver 334 disposes of the data in buffer B and marks the buffer as empty. DFN device driver 334 disposes of the data in

a full RL buffer and mark it as empty before the firmware fills the alternate buffer and flips back to the full one. If it does not, an overwrite error is generated by the card.

It is up to the user program to handle RL buffers. When the system first boots, the firmware and DFN device driver 334 are running and RL entries may be occurring. On a buffer full interrupt, DFN device driver 334 interrupt handler just marks the buffer as empty, effectively throwing away the data.

User programs that want to keep the RL data put DFN device driver 334 in an “RL save” mode. Then the user program gives DFN device driver 334 a pointer to a buffer that will get the contents of the full RL buffer. For example, during acquisition, user programs would keep RL data. DFN device driver 334 knows not to throw a full RL buffer away. The user program issues an RL read request. If a full RL Buffer exists (res. buffer A 738), the data is copied from the A buffer into the user buffer and then RL A 738 is marked as empty. If no full RL buffer exists, the read is marked as pending. Later, when an RL buffer (A) full interrupt occurs, DFN device driver 334 finds the pending read request. The data of Buffer A is copied into the user buffer and then A 738 is marked as empty.

If DFN device driver 334 is in an “RL save” mode and an RL buffer (A) full interrupt occurs with no outstanding user read request, the data is just left in the RL buffer until the user code reads it. If the user code does not try to read RL buffer A before RL buffer B fills up, an overwrite error is generated by the card.

### Detector Images

Detector images are written to memory above MAXMEM and also outside the 2 MByte DFN window. The DFN device driver 334 handles management of this area. Initially, the full region is free. As sequences are allocated, detector-sized buffers are used to hold images. Individual frames or entire sequences can be deleted during playback, which returns the memory to the free list. If a user program tries to allocate a sequence and there is not enough memory, an error is returned by DFN device driver 334. The user either deletes frames or sequences to free up enough

space. If no sequences are allocated, the user either adds more RAM to the system (and increase the PhysicalMemory/PhysicalMemorySize registry key) or reduces MAXMEM (and decrease the PhysicalMemory/Maxmem registry key). Reducing MAXMEM will affect WINDOWS NT ® performance. Whenever the registry is modified, the system is rebooted so that DFN device driver 334 uses the proper values.

### Programming DFN 304

DFN 304 controls image detection system 112 and acquires images from it over the image detection bus 377 to image detection system 112. A series of commands can be combined into an Event Queue program that is run by DFN 304 firmware. These commands are combined into a program called a sequence that is compiled into a common object file format ("COFF") file. The COFF file is loaded onto DFN 304 and a Begin Sequence command is issued to start it running. Several types of data are generated by a COFF file, set forth below.

The main result of a sequence is typically a set of x-ray images from image detection system 112. The x-ray images are DMA transferred from DFN 304 to computer RAM 334 as set forth above. When an image transfer completes, DFN device driver 334 receives a "DMA-done" interrupt. If the user code has previously issued a map request, the address of this arrived image is returned. The user code can display the image or do calculations on the data. When finished, the user code unmaps the image and asks for the next one. Unmapping an image does not delete it from computer RAM 334. An image will be destroyed during acquisition if it is overwritten in wrap mode or if a user explicitly deletes it during playback. A user program does not have to map images as they are being acquired. If there are enough frames in the sequence to hold all of the images generated by the COFF file, no errors will occur and the data will be in computer RAM 334. It can be mapped later during playback.

### Response Logs

The DFN firmware generates response log ("RL") entries during acquisition. RL entries hold information regarding images, DMA operations, the real-time bus, firmware state transitions, and errors. Some classes of RL entries are systematically generated while other classes are selectively turned on and off.

5                   When an RL buffer fills, an "RL-buffer-full" interrupt is sent to DFN device driver 334. If the user code has previously issued a read request, the contents of the RL buffer are copied to a user memory buffer, which was supplied as an argument to DFN device driver 334. The user code can store this buffer in a memory list until acquisition completes, write it to disk, or try to parse through it while acquisition is running. The user code then issues another RL read request to wait for the next full RL buffer.

10                   Response log buffers are different from detector images in that they are copied out of the memory above MAXMEM into user space. Images are left in the memory above MAXMEM and are simply mapped into user virtual address space. Therefore, the user is responsible for storing RL buffers or keeping them in memory.

15                   If the user cannot issue RL reads fast enough, an error occurs as described above. It may not be possible to write RL buffers to disk or to parse through them while data is being taken since this may take too much time.

### Host Flags

20                   A COFF file may need to notify or synchronize with the user. In this case, host flags are used perform the notification. User programs issue host flag read requests to see these flags. If a host flag has occurred, the host flag is returned on the read request. Otherwise, the read request is left pending until a host flag occurs or until image acquisition completes.

25                   Two different types of host flags are possible: notify and wait. A notify host flag is used to tell a user that an event has happened or a point has been reached in the COFF file. An interrupt is generated and the driver records an 8-bit

number associated with the host flag. If a host flag read is pending, this number is returned to the user. Otherwise, the number is stored until a read is issued. No further action is used with a notify host flag.

A wait host flag also tells the user that an event has happened or that a point has been reached in the COFF file, but the event queue is waiting for a response from the user. As with the notify flag, a wait flag generates an interrupt and the driver records an 8-bit number associated with the flag. The number is returned to the user via the host flag read request. The user then replies to the event queue using the same 8-bit number. Wait flags tell the user that some initialization process is finished. The user may, for example, then need to perform an action, such as perform an action on the image detection system 112 or position a target in some way. The queue does not continue until the user replies with the 8-bit wait host flag pattern. Accordingly, the queue and the user synchronize operations.

#### Errors

A variety of potential errors can happen during operation of DFN 304. Broadly, these errors are related to host flags, event queue, response logs, images (including acquisition, storage, and DMA), and fiber channel. More than one of each type of error class can occur at once. For example, if the fiber channel cable is disconnected, a bad receiver data, CRC, and sync loss errors could happen. A single return code is used to inform a user of such error(s). The user then asks the driver for a bitmask that gives a complete (extended) list. Errors of a particular class are returned on calls relating to that class. For example, the user is told that a host flag extended error happened on the Read and Set Host Flags calls to the driver. The software then handles data types and error processing in modular threads.

#### Acquisition of Data with Radioscopic Imaging System

Referring again to FIG. 15, a user controls imaging system 100 by writing a computer program, in the C language or equivalent, to control the system and acquire data. The user application loads a binary file, called a common object file



format ("COFF") file, into the EP EAB memory 474 using the acquisition DLL 313 and the DFN device driver 314. This binary file is created by a software program called event compiler 408. The binary file is used to generate the event queue. The event queue controls the x-ray generator and the acquisition of data from image detection system 112 over image detection bus 377.

Referring to FIG. 16, the event compiler 408 takes a Perl script as its input. Data from an Excel user interface 339 can alternatively be used to generate the Perl script with translator 331. Event simulator 407 and high resolution display 338 for event simulator 407 optionally receive the output from event compiler 408 for purposes of testing. User API 330 is a C program that accesses four libraries: 1) acquisition DLL 313; 2) display library 335 3) image process library 336; and 4) archive library 337. All libraries are optionally DLL libraries. Thus, the user application optionally links the libraries and does not recompile when recompiling the application program.

The user acquires images in several modes, which are controlled partly by the event queue (determined by binary file and Perl script 333) and partly by the user application program that uses the acquisition DLL 313, the DFN device driver 314, and the other libraries. The user can acquire single frames, multiple frames or can acquire frames continuously. This latter mode (called "fluoroscopy" or "wrap") is optionally used with a cardiac digital x-ray panel, where x-ray generation unit 203 fires at 30 frames/sec and data streams to DFN 304 and computer RAM 334 continuously. Since computer memory 334 is limited to, e.g. 1 GByte, computer memory 334 can hold 500 (16 seconds) of the 2 MByte frames. Hence, in this mode computer memory 334 is treated as a circular buffer and the last 16 seconds of data is retained in computer memory 334.

#### Driver Operating Scenario

By way of example, a user program that tests panels would need to make a series of calls to DFN device driver 314. This section gives a example of a data acquisition scenario and associated function calls.

1. The user first generates a COFF file that contains a series of commands to be executed on DFN event queue. This file is reused each time an acquisition is done.

2. The DFN 304 and image detection bus 377 are reset (IOCTL\_DFN\_RESET, IOCTL\_DFN\_RESET\_FC).

3. The frame and ROI sizes are read (IOCTL\_DFN\_GET\_ALLOCATION\_FRAME\_SIZE, IOCTL\_DFN\_GET\_ALLOCATION\_ROI\_SIZE) . If necessary, the frame and desired ROI sizes are set (IOCTL\_DFN\_SET\_ALLOCATION\_FRAME\_SIZE, IOCTL\_DFN\_SET\_ALLOCATION\_ROI\_SIZE).

4. The user allocates a sequence with the desired number of frames (IOCTL\_DFN\_ALLOCATE\_IMAGE\_BUFFERS).

5. The user makes the allocated sequence the current one (IOCTL\_DFN\_SET\_CURRENT\_SEQUENCE).

6. If desired, the user enables wrap mode on the sequence (IOCTL\_DFN\_SET\_SEQUENCE\_WRAP).

7. The COFF file is opened using the COFF file library routines.

8. The DFN 304 is put in NORMAL (or TEST) mode (IOCTL\_DFN\_SET\_MODE).

9. The card is programmed with the COFF file (IOCTL\_DFN\_PROGRAM\_DFN\_CARD).

10. The programming can optionally be verified (IOCTL\_DFN\_VERIFY\_DFN\_CARD\_PROGRAM).

11. The DFN 304 is told to start COFF file execution (IOCTL\_DFN\_BEGIN\_ACQ\_SEQUENCE).

5 12. Data acquisition has begun at this point.

a. In a separate thread, the user code can request map and unmap of image buffers (IOCTL\_DFN\_MAP\_BUFFER, IOCTL\_DFN\_UNMAP\_BUFFER). Note that mapping of buffers is done in ordinal order starting with 0. Unmap calls are also done in ordinal order starting with 0.

b. In another separate thread, the user code reads response log data (IOCTL\_DFN\_GET\_RESPONSE\_LOG) providing a buffer large enough to hold one full RL buffer (IOCTL\_DFN\_GET\_RL\_BUFFER\_SIZE).

c. In another separate thread, the user optionally posts host flag reads in case any are generated by the COFF file (IOCTL\_DFN\_GET\_HOST\_FLAGS).

d. If the user wants to end the acquisition early, the queue can be stopped (IOCTL\_DFN\_ABORT\_SEQUENCE).

14. When a COFF file completes, the original BEGIN\_ACQ\_SEQUENCE call will return with success. The card is in NORMAL (or TEST) mode.

15. The user can return the card to DIAGNOSTIC mode. The sequence size is read (IOCTL\_DFN\_QUERY\_SEQUENCE\_SIZE). Images can be mapped, viewed and/or archived, and then unmapped nonsequentially now that the system is not in real-time acquisition mode.

16. Unwanted frames can be deleted (IOCTL\_DFN\_DELETE\_FRAME, IOCTL\_DFN\_IS\_FRAME\_PRESENT). The sequence can be deleted from memory (IOCTL\_DFN\_DEALLOCATE\_IMAGE\_BUFFERS).

5 The following are function calls which may be made by a computer application to the acquisition DLL 313 to control detector framing node 304. Each DLL function call has an associated description.

#### DFNOpenSystem

Connect to DFN Driver and setup for image acquisition.

10

#### DFNCloseSystem

Clean up any loose threads and close the DFN driver connection.

#### DFNOpenSequence

Open the specified Event Sequence file and allocate image buffers.

#### DFNCloseSequence

15

Deallocate image buffers in PC memory.

#### DFNOpenArchiveSequence

Allocate image buffers but fill PC memory from previous archive.

#### DFNBeginSequence

Load and run specified Event Sequence COFF file.

20

#### DFNBeginSequenceNoMapping

BeginSequence without image mapping.

**DFNBeginSequenceNoMappingNoLog**

BeginSequence with no response log entries and no buffer maps.

**DFNBeginSequenceNoLog**

BeginSequence with no response log entries recorded.

5

**DFNWaitForSystemIdle**

Block until the end of the currently executing event sequence.

**DFNWaitTimeoutForSystemIdle**

WaitForSystemIdle until specified timeout has expired.

**DFNAbortSequence**

10

Terminate current sequence executing on DFN 304.

**DFNDeleteSequence**

Free-up allocated image buffers for the specified sequence.

**DFNGetSequenceName**

Return ASCII name of the sequence based on sequence ID.

15

**DFNRenameSequence**

Change the name of the sequence based on the sequence ID.

**DFNGetSequenceLengthAllocated**

Return number of image buffers allocated for the given sequence.

**DFNGetSequenceLengthAcquired**

Return actual number of images acquired for the given sequence.

DFNGetSequenceFrameSize

Return the actual frame size used for the given sequence ID.

DFNGetBeginSequenceTimeStamp

5 Return date and time when the given sequence was begun.

DFNGetCurrentSequenceID

Return the ID of the sequence currently selected.

DFNFindSequenceID

Return sequence ID corresponding to the ASCII string name.

10 DFNGetBeginSequenceTime

Return exact time (in seconds) that given sequence was started.

DFNSetArchiveSequenceTime

Set start time for previously archived sequence that is reloaded.

DFNGetExtendedErrorInformation

15 Returns extended error information for reported driver errors.

DFNHardReset

Unimplemented on DFN 304.

DFNSoftReset

Perform a state reset on DFN 304.

### DFNDetectorHardwarePresentSpecification

Turn on special driver mode to test DLL without DFN 304 present.

### DFNGetBoardVersionInfo

Return DFN board revision, serial number, and firmware revisions.

### 5 DFNGetDriverAndDLLVersions

Return software revision strings for DLL and Driver.

### DFNSelfTest

Request that DFN 304 perform a hardware Built In Self Test.

### DFNSendDetectorCommand

### 10 Send the specified Fiber Channel command to the detector.

### DFNResetFC

Reset the Fiber Channel chip-set directly.

### DFNAccessLocalBus

Read or Write to DFN local bus 384 directly.

### 15 DFNGetResponseLogSizeForSequence

Return number of response logs entries for given sequence ID.

### DFNGetResponseLogForSequence

Return all response log entries for the given sequence ID.

### DFNGetResponseLogSizeForFrame

Return number of response log entries for the given frame.

DFNBeginResponseLogChitchat

Start recording response log entries in Diagnostic Mode.

DFNEndResponseLogChitchat

5 Stop recording response log entries in Diagnostic Mode.

DFNForceRLBufferFlip

Force driver to return current active RL buffer and switch buffers.

DFNGetResponseLogForFrame

Return all response log entries for the given frame.

10 DFNGetResponseLogOfRunningSequence

Return specified section of currently active RL buffer.

DFNOpenSequentialPlaybackSequence

Open previously acquired sequence for sequential playback.

DFNOpenRandomPlaybackSequence

15 Select a sequence for random access using GetSpecificFrame.

DFNGetSpecificFrame

Return specified frame when in Random Playback Mode.

DFNGetNextFrame

Return most recent image and update the frame pointer.



**DFNDeleteFrame**

Remove specified frame from memory.

**DFNIsFramePresent**

Return whether or not specified frame exists in memory.

5

**DFNGetFreeFrameCount**

Return number of available empty frames in memory.

**DFNGetSequenceFrameRange**

Return Min. and Max. frame numbers still present in memory.

**DFNSetWrapMode**

10

Turn on/off wrapping of the circular image buffer.

**DFNIsWrapModeSet**

Check if Wrap mode is on or off.

**DFNIsWordSwapModeSet**

Returns state of WordSwap bit: 1=words swapped, 0=not swapped.

15

**DFNImageWordSwap**

Turn WordSwap on or off for mammography digital x-ray acquisition.

**DFNSetROI**

Unimplemented on DFN.

**DFNGetAllocationROI**

Unimplemented on DFN.

DFNGetSequenceROI

Unimplemented on DFN

DFNGetAllocationFrameSize

5 Return the frame size used to allocate memory for next acquisition.

DFNSetFrameSize

Set the detector frame size for use by the DFN during acquisition.

DFNImageReorder

10 Turn image reordering on/off. Applies to radiography digital x-ray panel 228 and cardiac/surgical digital x-ray panel 182.

DFNIsReorderModeSet

Check whether image reorder is turned on or off.

The following are EAB memory 474 (Event Queue) memory read/write function calls.

15 DFNLoadEvents

Download COFF file event instructions to DFN 304 directly.

DFNGetEventsFromEAB

Return Event Queue data from DFN EAB memory.

DFNGetEABMemSizes

20 Return the size in bytes of the DFN EAB(Event Queue) memory.

**DFNWriteEABMemory**

Write to specific address in DFN EAB memory.

**DFNReadEABMemory**

Read from a specific address in DFN EAB memory.

5

**DFNSetAutoscrubDelay**

Set the delay between autoscrub commands in  $\mu$ sec counts.

**DFNGetAutoscrubDelay**

Return the currently programmed autoscrub delay from the DFN.

**DFNEnableAutoscrub**

10

Turn on DFN-controlled autoscrub function.

**DFNDisableAutoscrub**

Turn off DFN-controlled autoscrub function.

**DFNReadRTBState**

Return snapshot of current state of real time bus lines.

15

**DFNSetRTBDirection**

Set direction of the real time bus lines independently.

**DFNSetRTBLine**

Force high or low values onto the real time bus lines independently.

The following are Host Flag Function Calls.

**DFNGetNextHostFlag**

Wait for next Host Flag from DFN Event Queue.

**DFNGetNextHostFlagTimeout**

GetNextHostFlag with timeout if Host Flag is not received.

5

**DFNSetWaitTypeHostFlag**

Signal DFN 304 using specified Host Flag.

The following are Queue Variable Function Calls.

**DFNChangeQueueVariable**

Change queue variable at specified address to specified value.

10

**DFNReadQueueVariable**

Returns the current value of queue variable at specified address.

The following are DFN Driver Function Calls.

**IOCTL\_DFN\_GET\_EXT\_ERROR\_INFO**

Returns extended error information for DFN errors.

15

**IOCTL\_DFN\_CLR\_EXT\_ERROR\_INFO**

Clears bits in the driver copies of the hardware error registers on DFN 304.

**IOCTL\_DFN\_BEGIN\_RL\_CHITCHAT\_MODE**

20

Begin recording response log data for asynchronous detector communication.

# IOCTL\_DFN\_END\_RL\_CHITCHAT\_MODE

End recording response log data for asynchronous detector communication.

# IOCTL\_DFN\_GET\_RL\_BUFFER\_SIZE

5 Returns the size in bytes of a response log buffer.

# IOCTL\_DFN\_GET\_RESPONSE\_LOG

Returns the next available full response log buffer.

# IOCTL\_DFN\_FORCE\_RL\_BUFFER\_FLIP

Causes DFN 304 to switch its current RL destination buffer.

10 **IOCTL\_DFN\_GET\_RL\_CLASS\_ENABLE\_MASK**

Returns the response log class entry mask showing which class(es) are currently reported.

# IOCTL\_DFN\_SET\_RL\_CLASS\_ENABLE\_MASK

15 Modify the response log class entry mask which determines which classes are recorded.

# IOCTL\_DFN\_ABORT\_RLREAD\_REQUESTS

Clears all response log read requests.

# IOCTL\_DFN\_GET\_FRAME\_SIZE

Returns the frame size for a sequence.

20 **IOCTL\_DFN\_GET\_ALLOCATION\_FRAME\_SIZE**

Returns the frame size that will be used in the next sequence allocation.

IOCTL\_DFN\_SET\_ALLOCATION\_FRAME\_SIZE

Sets the frame size for future sequences.

IOCTL\_DFN\_GET\_ROI\_SIZE

5 Returns the ROI size for a sequence.

IOCTL\_DFN\_GET\_ALLOCATION\_ROI\_SIZE

Returns the ROI size that will be used in the next sequence allocation.

IOCTL\_DFN\_SET\_ALLOCATION\_ROI\_SIZE

Sets the ROI size for future sequences.

10 IOCTL\_DFN\_ALLOCATE\_IMAGE\_BUFFERS

Attempts creation of an image sequence with specified number of buffers.

IOCTL\_DFN\_SET\_CURRENT\_SEQUENCE

15 Makes the sequence corresponding to the sequence identifier the current sequence.

IOCTL\_DFN\_DEALLOCATE\_IMAGE\_BUFFERS

Frees all image buffers and sequence information associated with an allocated sequence.

IOCTL\_DFN\_SET\_IMAGE\_REORDER

20 Forces reordering on a sequence regardless of registry default.

**IOCTL\_DFN\_CLR\_IMAGE\_REORDER**

Forces no reordering on a sequence regardless of registry default.

**IOCTL\_DFN\_QUERY\_SEQUENCE\_SIZE**

5 Returns number of frames in the sequence and other information of the sequence.

**IOCTL\_DFN\_DELETE\_FRAME**

Deletes frame specified by the ordinal frame number from the current sequence.

**IOCTL\_DFN\_IS\_FRAME\_PRESENT**

10 Reports whether specified frame number is present in the current sequence.

**IOCTL\_DFN\_GET\_FREE\_FRAME\_CNT**

Returns the number of frames of specified size available in free memory.

15 **IOCTL\_DFN\_MARK\_ARCHIVE\_SEQUENCE**

Force immediate map request completion when filling a sequence from an archive.

**IOCTL\_DFN\_SET\_SEQUENCE\_WRAP**

Define a sequence to be operable in wrap mode.

20 **IOCTL\_DFN\_GET\_CURRENT\_SEQUENCE\_ID**

Returns the sequence identifier of the current sequence.

**IOCTL\_DFN\_MAP\_BUFFER**

Returns an address for the image buffer specified in the current sequence.

**IOCTL\_DFN\_UNMAP\_BUFFER**

5 Unmaps the specified image buffer in the current sequence.

**IOCTL\_DFN\_DELETE\_ALL\_SEQUENCES**

Deletes all sequences allocated by the driver.

**IOCTL\_DFN\_SET\_DETECTOR\_WORDSAP**

Forces pixel word swapping on a sequence regardless of the default.

10 **IOCTL\_DFN\_CLR\_DETECTOR\_WORDSAP**

Forces no pixel word swapping on a sequence regardless of the default.

**IOCTL\_DFN\_RESET**

Resets the DFN board firmware.

**IOCTL\_DFN\_RESET\_FC**

15 Resets the Fiber Channel hardware.

**IOCTL\_DFN\_GET\_VERSION\_INFO**

Returns DFN 304 version and S/N, as well as firmware revision numbers for EP 374 and DAP 372.

**IOCTL\_DFN\_GET\_EAB\_MEM\_SIZES**



Returns the size of EAB memory and of the individual queue areas within it.

#### IOCTL\_DFN\_WRITE\_EAB\_MEMORY

Data can be written to EAB memory 474 with this command.

#### 5 IOCTL\_DFN\_READ\_EAB\_MEMORY

Data can be read from the EAB memory on EP 374 with this command.

#### IOCTL\_DFN\_PROGRAM\_DFN\_CARD

10 Programs EAB memory 474 with code from the user generated COFF file.

#### IOCTL\_DFN\_VERIFY\_DFN\_CARD\_PROGRAM

Returns the code in EAB memory 474 that was programmed previously.

#### IOCTL\_DFN\_GET\_GEN\_DATA\_CFG

15 Returns configuration settings for the Test Image Generator circuit on DFN 304.

#### IOCTL\_DFN\_SET\_GEN\_DATA\_CFG

Sets specified configuration settings for the Test Image Generator on DFN 304.

#### 20 IOCTL\_DFN\_BEGIN\_ACQ\_SEQUENCE

Starts the event queue and begins data acquisition.

#### IOCTL\_DFN\_ABORT\_SEQUENCE

Stops the currently running DFN acquisition before an EndQ is received.

#### IOCTL\_DFN\_SET\_AUTOSCRUB\_DELAY

Sets the delay between consecutive autoscrub requests in 2  $\mu$ sec clock  
5 ticks.

#### IOCTL\_DFN\_GET\_AUTOSCRUB\_DELAY

Returns the delay between consecutive autoscrub requests in 2  $\mu$ sec  
clock ticks.

#### IOCTL\_DFN\_ENABLE\_AUTOSCRUB

10 Turns on the autoscrub circuit on DFN 304.

#### IOCTL\_DFN\_DISABLE\_AUTOSCRUB

Turns off the autoscrub circuit on DFN 304.

#### IOCTL\_DFN\_CONFIG\_RTБ

15 Sets the default state and driver direction for the real time bus on DFN  
304.

#### IOCTL\_DFN\_READ\_RTБ

Returns the current state of the real time bus lines including the default  
and direction settings.

#### IOCTL\_DFN\_WRITE\_RTБ

20 Writes data to the real time bus 379 in the State/Mask format used by  
the Event Queue.

**IOCTL\_DFN\_GET\_MODE**

Returns the current state (Normal, Run, Diagnostic) of EP state machine.

**IOCTL\_DFN\_SET\_MODE**

5 Sets the current state (Normal, Run, Diagnostic) of EP state machine.

**IOCTL\_DFN\_GET\_HOST\_FLAGS**

Reads host flags from the event queue.

**IOCTL\_DFN\_SET\_WAIT\_HOST\_FLAG**

Block while waiting for the specified Host Flag from the event queue.

10 **IOCTL\_DFN\_CLR\_ALL\_HOST\_FLAGS**

Clears any outstanding Host Flags or Host Flag requests.

**IOCTL\_DFN\_ACCESS\_LOCAL\_BUS**

Read or write the DFN local bus is while the card is in Diagnostic mode.

15 **IOCTL\_DFN\_SEND\_DETECTOR\_CMD**

Send commands directly to the detector while in Diagnostic mode.

**IOCTL\_DFN\_SEND\_DFN\_CMD**

Bypass the driver to Execute a DFN command directly in Diagnostic mode.

20 **IOCTL\_DFN\_SET\_TRACE\_LEVEL**

Sets the debug trace level which controls printing of trace messages by the kernel debugger.

#### IOCTL\_DFN\_GET\_TRACE\_LEVEL

5 Returns the debug trace level controlling printing of trace messages by the kernel debugger.

#### IOCTL\_DFN\_BUGCHECK

Force a system crash in order to generate a crash dump for analysis.

#### IOCTL\_DFN\_SET\_BREAK\_FLAG

Causes driver checked version to break on entry to every function.

10 IOCTL\_DFN\_CLEAR\_BREAK\_FLAG

Causes driver checked version to NOT break on entry to every function.

#### IOCTL\_DFN\_DUMP\_HEAP\_LIST

15 Dumps information of free memory heap and sequence memory usage to an output file.

#### IOCTL\_DFN\_SET\_\_LEDS

Turns DFN LEDs on or off independently according to the specified state.

#### IOCTL\_DFN\_GET\_BASE\_ADDRESSES

20 Returns kernel virtual addresses so user application can access DFN memory space directly.

#### IOCTL\_DFN\_FREE\_BASE\_ADDRESSES

Releases the specified kernel virtual addresses.

IOCTL\_DFN\_DUMP\_DFN\_MEMORY

Writes a section of DFN memory to a file.

IOCTL\_DFN\_MAP\_PHYS\_ADDR

- 5                   Maps a physical address to a user virtual address; used to access RAM above MAXMEM.

IOCTL\_DFN\_UNMAP\_PHYS\_ADDR

Release the specified user virtual address.

IOCTL\_DFN\_READ\_DFN\_ADDR

- 10                   Attempts to read the DFN board at the offset given in the input argument.

IOCTL\_DFN\_WRITE\_DFN\_ADDR

Attempts to write a value to the DFN board at the offset given in the input argument.

- 15                   IOCTL\_DFN\_GET\_FC\_LOOPBACK

Returns the state of Fiber Channel loopback; 0=loopback disabled, 1=loopback enabled.

IOCTL\_DFN\_SET\_FC\_LOOPBACK

- 20                   Enables or disables Fiber Channel loopback; 0=loopback disabled, 1=loopback enabled.

As this invention may be embodied in several forms without departing from the spirit or principal characteristics thereof, the present embodiments are

therefore illustrative and not restrictive. Those skilled in the art will appreciate that changes may be made to these embodiments without departing from the principles and spirit of the invention. Accordingly, the scope of the invention is defined by the appended claims rather than by the description preceding them, and all changes that

5 fall within the metes and bounds of the claims, or equivalents of such metes and bounds thereof, are therefore intended to be embraced by the claims.